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TEST DIRECTOR'S REPORT ON OPERATION PLUMBBOB

5 November 1957

University of California
Radiation Laboratory
Livermore Site
Livermore, California

NOTICE

This is an extract of the **Test Director's Report on Operation PLUMBBOB**, which remains classified **SECRET/RESTRICTED DATA** as of this date.

Extract version prepared for:
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DEFENSE NUCLEAR AGENCY
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this report is to review in perspective and to present concisely in usable form significant aspects pertinent to Operation PLUMBBOB. The Summary is a succinct report of the entire Operation. The Chapters following the Summary merely amplify its content. Chapter I establishes the inter-relationship and functions of the several groups participating under the Test Director. Chapter II is the main chapter of the report and is intended to stand alone as a report of the scientific aspects of the Operation, particularly in regard to the objectives, techniques, results, conclusions and recommendations stemming from the scientific program. Chapter III presents a discussion by the

staff sections of the administration of the Operation and is intended to include not only historical documentation but also information useful in planning future operations. The Summary and Chapters of the report are sufficiently independent that the reader need only dwell on that portion which is of particular interest to him.

FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is all currently classified as Restricted Data or Formerly Restricted Data under the provision of the Atomic Energy Act of 1954, (as amended) or is National Security Information.

This report has been reproduced directly from available copies of the original material. The locations from which material has been deleted is generally obvious by the spacings and "holes" in the text. Thus the context of the material deleted is identified to assist the reader in the determination of whether the deleted information is germane to his study.

It is the belief of the individuals who have participated in preparing this report by deleting the classified material and of the Defense Nuclear Agency that the report accurately portrays the contents of the original and that the deleted material is of little or no significance to studies into the amounts or types of radiation received by any individuals during the atmospheric nuclear test program.

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Note: For amplified reports of Operation Plumbbob, see current issue of "Status of WT Reports," M-5440, issued by AEC, Technical Information Service Extension, Oak Ridge, Tenn.

LIST OF ILLUSTRATIONS

PREFACE

A weapons test operation such as Operation Plumbbob is dynamic in its many facets. Like an all-star game, the efforts of many discrete organizations are fused to produce a team striving to achieve common and related objectives. The opponent of this team—Time—is uncompromising and unsympathetic toward the myriad problems that plague those conducting the Operation. This is an atmosphere that challenges patience, ingenuity, tact and the orderly process of technical progress.

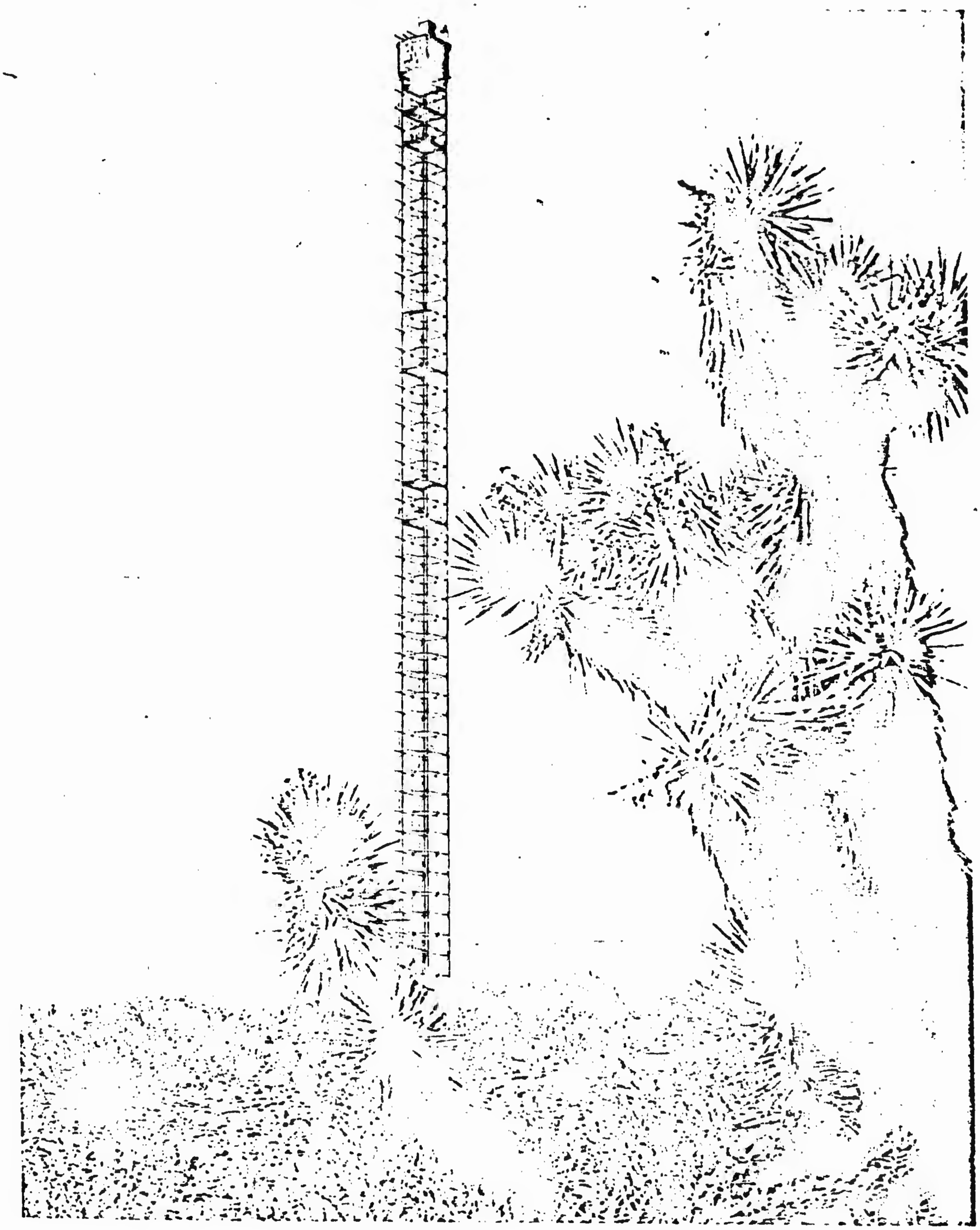
By comparison with the conduct of the Operation, the reporting of that Operation becomes a tedious task, both to those charged with the preparation of the report and to many of those who must review and interpret its content. Recognizing this, an attempt has been made to make this report of Operation Plumbbob as comprehensive, interesting and useful as possible.

The purpose of the report is to review in perspective and to present concisely in usable form significant aspects pertinent to Operation Plumbbob. The Summary is a succinct report of the entire Operation. The Chapters following the Summary merely amplify its content. Chapter I establishes the inter-relationship and functions of the several groups participating under the Test Director. Chapter II is the main chapter of the report and is intended to stand alone as a report of the scientific aspects of the Operation, particularly in regard to the objectives, techniques, results, conclusions and recommendations stemming from the scientific program. Chapter III presents a discussion by the staff sections of the administration of the Operation and is intended to include not only historical documentation but also information useful in planning future operations. The Summary and Chapters of the report are sufficiently independent that the reader need only dwell on that portion which is of particular interest or use to him.

It is appropriate to acknowledge the willing cooperation and generous support of the many contributors to this report. Chapter II includes the reports of the individual Test Groups as submitted by their Directors, Dr. W. E. Ogle of the LASL; Dr. H. B. Keller and Dr. C. E. Violet of the UCRL; Mr. R. L. Corsbie of the CETG; Col. K. D. Coleman of the DOD; Mr. J. H. Scott of Sandia; and Dr. J. D. Shreve of TG57. Too, several members of the Test Director's staff were particularly instrumental in generating this report. These include Mr. D. B. Shuster of Sandia, the Associate Test Director; Mr. Vern Denton of UCRL, the Staff Coordinator; Col. W. S. Hutchinson, AFSWP, the Military Assistant to the Test Director; Mr. R. A. Lusk (S-1) of EG&G; Mr. G. P. Stobie (S-3) of Sandia; Mr. C. M. Bacigalupi (S-6) of UCRL; Mr. W. E. Nolan of UCRL, the Rad-Safe Advisor; and Mr. E. L. Brawley of AEC, ALO, the Safety Advisor. Mr. H. E. Grier of EG&G reported EG&G's scientific support, and Mr. E. L. Jenkins of Sandia information on assembly and arming. Mr. R. A. Lusk of EG&G performed the task of coordinating and editing the report as presented in the pages that follow.

G. W. Johnson

G. W. Johnson



CONTINENTAL NUCLEAR TESTING IN THE NEVADA DESERT

SUMMARY

Operation Plumbob was designed to conduct experiments aimed at advancing technical understanding of nuclear and thermonuclear weapons, to test prototypes and mockups of weapons, and to develope further information on their military and civil effects, including studies of basic phenomenology of exposions. In addition to the basic purposes of the operation, advantage was taken of detonations to provide training for military and civil effects groups under field conditions.

During the course of the operation, new test techniques were developed which permit greater flexibility in utilization of the Nevada Test Site, the two major steps being the use of captive balloons and the firing of a device underground.

SCIENTIFIC DEVELOPMENT OF WEAPONS

The weapons development program of the Los Alamos Scientific Laboratory (LASL) and the University of California Radiation Laboratory (UCRL) was directed toward the following objectives:

1. To secure weapons of smaller size and greater delivery capability.
2. To achieve a greater economy in the use of active materials.
3. To continue development of weapons having a high safety factor in handling, storage and delivery.
4. To secure basic information on higher yield designs for devices and weapons which will later be tested in the Pacific.

During Plumbbob progress was made toward all these objectives. In several systems successful tests produced data which will permit the design of weapons with optimized investments in fuel.

Sandia conducted an experiment (1) to continue the exploration of the effects of close-in fireball phenomena on basic materials; (2) to continue exploration of the effects of close-in fireball phenomena on weapon components; and (3) to gain further understanding of fireball physics.

Basic materials studies were made by exposing samples at distances ranging from 50 to 2800 feet from a 10-kiloton burst.

Measurements of neutron and gamma fluxes and of overpressures and dynamic pressure in connection with the above studies were made. A free field study of the neutron flux as a function of height above the ground surface was also carried out.

MILITARY WEAPONS EFFECTS

The weapons effects program of the Department of Defense was directed primarily toward the study of blast and shock phenomena, the response of structures in the overpressure region above 50 psi, and a biomedical program. In addition, information was collected on induced

radioactivity, on electromagnetic signal generation by a detonation, and on the propagation of electromagnetic radiation in the ionized region surrounding a detonation. One shot fired in mountainous terrain led to measurements of shock and blast effects under such conditions. An air-to-air delivery of an MB-1 rocket with a nuclear warhead provided information on nuclear and blast inputs necessary to establish delivery criteria.

Principal effort in the study of strong shocks was expended on the Priscilla shot, a 36-kiloton-yield shot from a 700-foot balloon centered in the Frenchman Flat area. Successful measurements were obtained for peak overpressures from 510 psi downward. The first experimental confirmation was obtained of the expected sharp drop in dynamic pressure in the region of regular reflection; the closest reading to ground zero was 280 psi at 350 feet, whereas the peak reading, 510 psi, occurred at 850 feet. Studies of precursor phenomena revealed that tower shielding may inhibit the formation of a precursor. Extensive measurements of earth shock induced by air blast and its effects were carried out. Measured values of accelerations agreed with predictions in the first 10 feet of depth, but there were discrepancies in the next lower 20 feet, which may have resulted from inhomogeneities in the soil. Vertical earth displacements produced by the shock wave were measured down to 200 feet and typical surface values observed were 14 inches at 270 psi and 2 inches at 60 psi.

Terrain effects were determined on the Smoky event, a 43-kiloton-yield shot from a 700-foot tower located near foothills. The results may be summarized as follows:

1. Overpressures on front slopes were higher than on flat terrain at the same distances; pressure on back slopes of a 550-foot hill were lower than corresponding flat terrain pressure, whereas those of a 280-foot hill were higher.

2. Overpressures on low, rolling terrain were higher than flat terrain pressures for like distances; dynamic pressures were lower.

3. Dynamic pressures on front slopes of high ridges were lower than flat terrain pressures at corresponding distances and fell sharply below flat terrain pressures on back slopes.

4. The wave forms on all front slopes had shorter rise times than the corresponding wave forms on flat terrain. Wave forms on back slopes were nearly ideal.

The nuclear radiation effects measurements were successful, indicating that neutron-induced soil activity is a definite tactical hazard at early times. The primary isotopes which add to the radiation field are Na^{24}, Mn^{56}, and Al^{28}. The induced activity was observed to be primarily generated by thermal neutrons, but higher energy neutrons also contributed. The effect of increased moisture was to increase the intensity of the fields, although the effect is not as critical as had been expected.

Prompt neutron dosages were found to depend strongly on weapons design and valuable numerical results were obtained for several designs.

From the initial gamma radiation measurements, it was found that the total gamma radiation dose increased with altitude to 400 feet, where about 30 percent more was received than on the surface at the same distance from point of detonation.

Measurements of shielding afforded by underground shelters yielded useful data on shielding factors in the main structures and entry ways.

Results of the structures program contributed significantly to understanding loading and response of surface and underground structures in the overpressure regions above 50 psi. Generally the underground structures tested sustained less damage than predicted, from which it was concluded that design assumptions upon which the structures were constructed and analyzed were more conservative than necessary. It was shown that underground arch-type shelters are the most efficient and can be constructed readily to withstand overpressures up to 200 psi. For above-surface structures, arch or dome types can be designed to survive up to 70 psi.

The biomedical program succeeded in providing information on: (1) effects of nuclear weapons on large animals (swine); (2) eye protection provided by an electromechanical shutter; and (3) casualty effects of missiles translated by a shock wave.

Under experimental conditions involved in the mass casualty studies on a large number of pigs, animals suffering missile wounds from glass, in most instances, received lethal doses of radiation. Many of the animals received serious thermal burns. There was an inverse association between degree of burn and survival time of the exposed animals. Certain clearcut conclusions were reached: namely, for a large biological specimen in the open, within the precursor of a nuclear weapon, the primary cause of death is by mechanical injury to the organisms due to translation with nearly 100 percent being killed

instantly. Outside the precursor region, temporary survival may be expected in the open, but barring total missile injury, the radiation levels are lethal. Close-in foxholes may provide protection to prevent total injury from blast and burn, but lethal radiation dosages will also be received.

Preliminary results give an LD/50/30 for pigs to be about 500 rep gamma rays plus neutrons, which agrees with laboratory results but disagrees with earlier field results.

The electromechanical shutter, with a response time of 0.5 milliseconds gave complete protection from chorioretinal burns and flash blindness. A goggle can now be designed for service testing.

Preliminary field analysis of data collected in the aircraft structures program indicates objectives of the various aircraft studies were successfully met except for the airship project, where further detailed analysis is required. Basic objectives were to determine safety delivery criteria for nuclear weapons.

Delivery of the air-to-air missile by an F89D gave information on thermal radiation, nuclear radiation, and blast inputs and responses. Data were obtained on effects of gust loads imposed on maneuvering loads. Measurements on other events were made with airships, HSS-1, FJ4, and A4D-1 aircraft.

The results of a mine clearance study using a field of live and inert mines proved that the methods used to predict actuation are reliable. In addition, details were obtained on the effects on actuation resulting from depth of burial and wave form of shock.

The program to measure electromagnetic effects led to successful measurements of the azimuthal, radial and vertical components of the magnetic field in the frequency region up to 200 kc. The strongest component was azimuthal and the field dropped by an order of magnitude in less than 100 microseconds.

Investigation of the effects due to a nuclear cloud on propagation of radio and radar signals from an aircraft transmitter to ground receivers failed to show any attenuation after H + 1 minute at several frequencies from 4 mc up to 9200 mc. Radar tracking of an aircraft at H + 3 and H + 5 minutes through a nuclear cloud using X-band radar was successful. However, radio wave transmission at very early times from within the ionized volume generated by a nuclear detonation did not prove feasible.

A project involving long-range detection and location of nuclear detonations over distances of several hundred miles gave fixes to within 0.8 miles and times of detonation with an error of less than 6 milliseconds. Pulses observed from lightning transients showed that i consistent patterns peculiar to wave forms, fie intensities, or pulse durations of these transien could distinguish them from the electromagnet pulse of a nuclear detonation.

CIVIL EFFECTS

The Civil Effects Test Group (CETG) pr gram broke into six major categories: (1) studi of fallout; (2) biomedical and physical aspects prompt gamma and neutron radiation; (3) bla effects on structures; (4) biomedical effects blast; (5) radiological contamination, decor tamination and training, and (6) instrument tion and supporting services.

Extensive studies were made of fallout wit emphasis on documentation of the fallo patterns out to 600 miles from ground zero b aerial monitoring and ground survey, and detai ed analysis of the fallout material to determir its physical and chemical properties. Include were studies of changes in nature of fallo material with time, particle size distribution an the availability of radioactive material to the bic sphere.

Measurements were obtained of shieldin afforded by structures, and also pertinent t the shielding program itself, extensive evaluatio of the angular distribution in air of bomb radia tion was successfully accomplished. Ultimatel it is hoped these data will be effective in permit ting the establishment of individual dosage received by Japanese survivors.

Associated with the precise measurement of radiation dosages were the exposure of larg and small animals to prompt bomb radiation Mice, monkeys, swine, and burros were utilize to develop interspecies relationships and to cor relate Plumbbob results with data obtained i earlier test series.

The CETG structures program resulted i important measurements concerned with desig of reinforced concrete dome shelters, a dual purpose garage shelter, a family shelter, a mo dular brick building, and an array of shelter designed by engineers in France and Germany Also in the program were studies of doors, an anti-blast valves for ventilating systems.

The biological program was concerned witl the biological response to various patterns o overpressure, the effects of missiles and th effects of physical displacement of the biologica target by blast-produced winds. Closely associat ed were measurements of blast inside oper structures to provide data for design of shelter not requiring doors.

SUMMARY

A radiological defense experiment was conducted successfully in which Civil Effects Test personnel occupied a protective shelter in a region of heavy fallout. Methods of determining the magnitude of the radiation field and procedures for leaving the shelter and recovering a working area were effectively demonstrated.

The CETG sponsored a group of training exercises to provide experience in contaminated areas for radiological defense leaders selected from State and local civil defense organizations.

A system of remote gamma radiation monitoring was carried out at stations from 30 miles out to 300 miles. Offsite radiation intensities resulting from fallout could be learned simply by dialing the station through the telephone network, the station automatically replying with a coded signal giving the radiation level. A pilot effort utilizing this equipment on-site conclusively demonstrated that early data on close-in radiation intensities can be obtained without the exposure of human monitors. The significance of these results point to practical methods of reducing radiation exposure to participants in both test and civil activities associated with nuclear reaction.

A last minute addition to the Plumbbob Operation was the investigation of plutonium contamination from one-point detonation

on the ground in the open. The test preceded all nuclear shots and was conducted in Groom Valley adjacent to but northeast of NTS proper.

Four experimental programs were examined:

1. Constitution of the cloud and the physics of fallout from and redistribution after such a burst.
2. The inhalation hazard to animals from both cloud passage and material resuspension post deposition.
3. Means of monitoring and decontaminating plutonium ladened pavings, building materials and ground surfaces.
4. The execution and evaluation of field alpha instrument surveys.

Scientific data on fallout and inhalation hazard were obtained through the use of sticky pans, acute air samplers and lung models. Successful decontamination methods were developed resulting in cleanup of up to 99 percent of the original plutonium bearing contaminants from hard surfaces.

Animal exposures, air sampling and surface wind recordings were continued for six months post shot. Periodically during this time, soil sampling, decontamination experiments and alpha field monitoring were done also.

NEW TEST TECHNIQUES

Two new test techniques were tried during the operation — namely, the use of captive balloons and firing underground. The captive balloon system was developed by Sandia prior to the operation and was successfully used throughout. The underground shot was fired near the end of the operation and was purely a test of the confinement design and of the measurement methods.

The balloons were used to support loads weighing from 1800 to 4400 pounds at elevations of 500 to 1500 feet above ground level. Balloon positioning could be held to plus or minus 30 feet at a 1500-foot altitude in winds up to 20 miles per hour. While pretest balloons flew repeatedly in winds of 35 to 45 miles per hour, it was decided that for safety and handling ease they should not be used operationally with wind velocities greater than 20 miles per hour.

The balloon was raised and lowered by winches operated remotely from the control point. The position and behavior of the balloon, and the wind speed at balloon altitude all were monitored at the control point.

Use of balloons reduced the close-in local fallout to a few percent of that for tower shots.

The entire system was highly successful and, in fact, made possible the accomplishment of the Plumbbob program. The success is confirmed by the fact that 12 of the 24 full-scale nuclear detonations fired above the surface were fired from balloons.

The underground shot of 1.7-kiloton yield at a depth of 900 feet verified the calculations with respect to containment instrumentation. As a result of the firing it has been established that, for soil conditions similar to NTS, shots can be contained at shallower depths calculated to be 450 $W^{1/3}$ feet, where W is the yield in kilotons. No detectable radioactivity was vented at any point. After the detonation the tunnel was re-entered and it was possible to proceed on foot to within 200 feet of the detonation point. At this distance the tunnel was partially collapsed and full of broken rock, but there was no detectable radioactivity. However the gaseous remains of the explosion resulted in a high concentration of carbon monoxide which required re-entry precautions. There were no offsite effects and the seismic signals could not be felt at a distance of 2.5 miles. The general feasibility of the method was proved and as a consequence plans are being developed for further underground tests.

A new problem in decontamination was presented by the balloon operation. Generally, the balloons were fired, as planned, at altitudes such that the fission product fallout was small. However, in some cases the activity induced by

neutron absorption in the soil was as high as several hundred roentgens per hour at one hour. Since the balloon sites were required for repeated firings it was important to consider decontamination procedures. A major difference was apparent between such contamination and fission product fallout — mainly that the neutrons were absorbed in a relatively thick layer so that earth removal methods would require the movement of one to two feet of soil — an unwieldly operation — as compared with only surface contamination resulting from fallout. In some cases, an equivalent amount of unactivated earth was placed over the area to provide shielding, but here again a large amount of earth moving was required. To study methods of reducing this problem, an experiment using a boron-containing mineral incorporated in the first two feet of soil was carried out with encouraging results.

SCIENTIFIC SUPPORT

Edgerton, Germeshausen, & Grier provided timing and firing, scientific photography, alpha and other radiation measurements. A capability was developed in the timing and firing systems to fire one or all of three possible shots simultaneously; however simultaneous firing was not in fact accomplished because of radiochemical sampling requirements. Timing signals were provided by both hardwire and radio. Major task of the photographic unit was to measure fireball growth for yield, growth and motion of atomic cloud after shock breakaway, and position of burst for the air-to-air missile. Photographs were also made for DOD and CETG to determine effects of blast and thermal radiation on structures and materials.

Reaction history measurements were made by the EG&G alpha group for the Los Alamos Scientific Laboratory (LASL). The measurements included neutron multiplication rate throughout the entire measurable history, and nuclear pulse for safety shots,

EG&G developed a simplified recording system for these measurements. Improvements were made in the image converter streak camera, which is smaller and more portable than cameras of this type used before.

ORGANIZATION

Because of the magnitude of the technical program and the large number of participating groups, a problem in organization needed to be faced. It was decided to develop a joint operating staff in support of the six major technical groups (CETG, Sandia, UCRL, LASL, DOD, and TG57). A joint staff composed of members from EG&G for S-1 (Administrative Services), Sandia for S-3 (Plans and Operations), ar UCRL for S-6 (Construction), was establishe for the Test Director. The purpose of the joi staff was to provide coordination and to serv as a link with the support organization to ob tain necessary services for the Test Groups. Th form of Test Director staff organization wa something of an experiment for Nevada testin and proved to be strong and successful.

Included in the organization was the Armin group, which was responsible to the Test Di rector for arming and disarming devices. I addition, the group monitored firing system to assure that operating specifications were me with respect to outputs, reliability and safety

A new office, that of Military Assistant to the Test Director, was established for this opera tion. The office proved to be a valuable aid in developing and maintaining mutual appreciation of problems involved in military effects and training programs. Because of the existence o the office, many operational difficulties were quickly resolved.

The Test Director was responsible for al on-site Rad-Safe except that for post-Project 57 and Exercise Desert Rock. Support was provided by the Support Director through the facilities of Reynolds Electrical & Engineering Company on-site Rad-Safe unit. The results of Rad-Safe operations were extremely gratifying because out of some 4,000 participants at the test site for extensive periods of time, only 14 exceeded 3R for any 13-week period, and no person exceeded 5 R for the operation.

Each Test Group had responsibility for execution of its respective programs in the field. Each group had its own staff to take care of problems peculiar to the group and to coordinate mutual requirements and problems with the Test Director's Staff.

New safety problems were encountered in balloon operations and underground firing and recovery. These were carefully reviewed by the Safety Office of the Test Director and effective procedures developed in consultation with the responsibile operators in each case.

Overall, the major objectives of Plumbbob were accomplished by all participating Test Groups. The major difficulties that arose during the operation had to do mostly with changes in schedule. As in all previous operations, a schedule of firing dates was established in advance. These dates, though viewed as optimistic, were intended to serve as guides to all participating groups for planning purposes. During the course of an operation it is always necessary for a variety of reasons to change ready dates, and in the interests of economy and efficiency, it is important that all participating groups have as

much built-in flexibility time-wise as possible. The operation could have been shortened had it been possible to get agreement among the major users prior to the operation with respect to starting date; however it is important to observe that there were good programmatic reasons for the schedule as developed. Nevertheless, as a result, the operation started approximately one month before the test organization as a whole was ready to proceed. There were occasions in which shot schedules were changed on unnecessarily short notice. These conditions caused hardship for some participating groups but in no case was critical information lost because of firing.

One way in which greater flexibility of firing could be achieved in future operations would be for users participating on a "non-interference basis" to limit their participation to the minimum number of detonations. Flexibility was usually lost because of the large number of participants involved on a given shot. It is quite clear that no major element can actually participate on a non-interference basis.

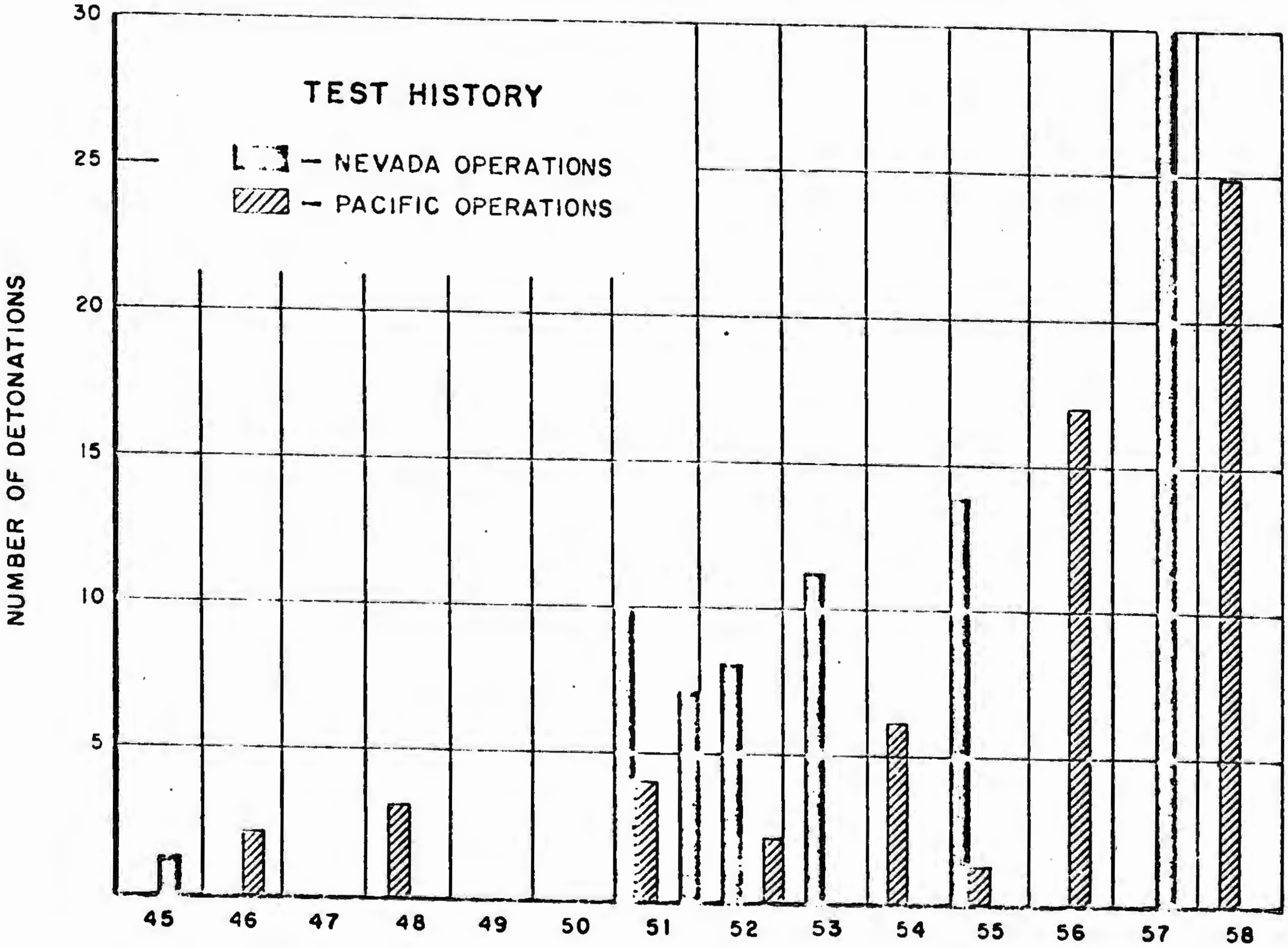
At the start of the operation, the experimental groups required a large number of dry runs involving complete operation of the signal systems. As the operation progressed the number of these runs was gradually decreased, which greatly reduced the burden on EG&G and the Test Director's Staff.

No major problems were encountered in housing or vehicles.

The basic organization established for the Plumbbob Operation was consistent with the desires of all users. The major strength for accomplishment of technical measurements should and did reside within the technical Test Groups. In some instances additional staff support was required and obtained.

The construction and support contractors met and in some cases exceeded schedules. For example, towers were ready early in some instances but inflexibility in some Test Groups prevented full advantage being taken of the possible time savings.

Within the body of this report are numerous, specific, detailed recommendations with respect to improving joint operations in Nevada. It is hoped this record will be useful in future planning of such operations.



CHAPTER I
TEST DIRECTOR'S ORGANIZATION AND FUNCTION

A. TEST DIRECTORSHIP

A. TEST DIRECTORSHIP

The Test Director is responsible for the overall coordination and support of the entire scientific test program. His office is responsible for organizing and carrying out plans of the users of the Site as coordinated through the Nevada Planning Board and as approved by the Test Manager. The Test Director reviews the state of preparations at all times, and upon evaluation expedites conditions, where necessary, in order that the test schedule may be met. His office assures that personnel using the Site have the necessary facilities to live and to perform their work. The office resolves differences between the various Site users and assists, where required, in carrying out the plans of all users. The Test Director determines experimental state of readiness by discussion with the participating agencies, and advises the Test Manager when that readiness is such that firing can proceed.

To insure the most effective utilization of support facilities available, the requirements of numerous Site users have to be met on as equitable a basis as possible. To achieve the maximum cooperation of test participants, it was deemed desirable for Operation Plumbbob to have the office of the Test Director staffed by personnel drawn from several of the participating agencies. Thus, with Dr. G. W. Johnson of UCRL as Test Director, and Mr. D. B. Shuster of Sandia as Associate Test Director, EG&G, Inc., was asked to staff the S-1 function, Sandia the S-3 function, and UCRL the S-6 function. Such staffing resulted in a close liaison between the Test Groups and the office of the Test Director and did, in fact, yield the understanding cooperation desired.

B. STAFF SECTIONS

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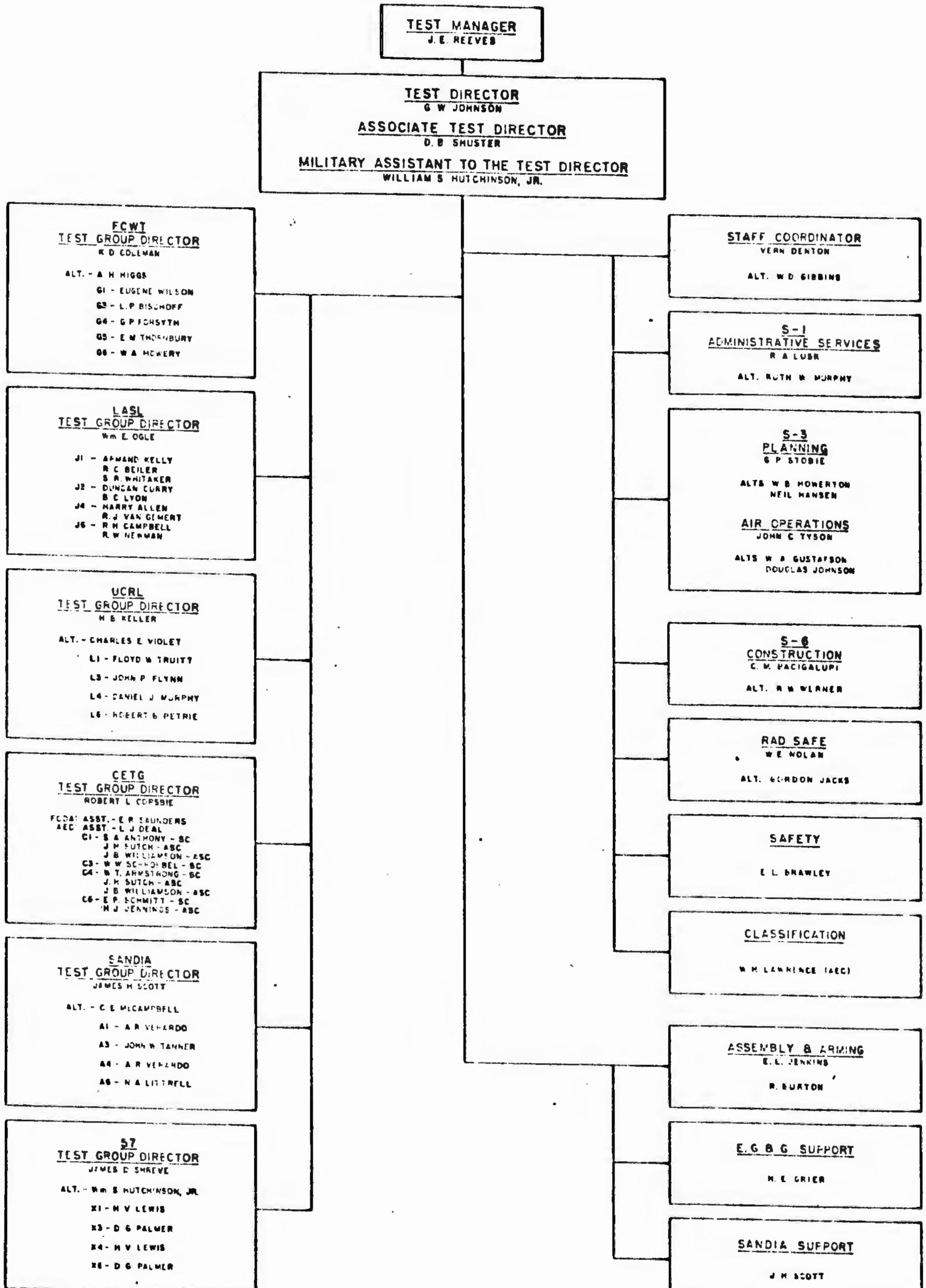
The Test Director and the Associate Test Director were assisted in the execution of their duties by a staff comprised of a Staff Coordinator, an Administrative Staff (S-1), a Plans and Operations Staff (S-3), and a Construction Staff (S-6). In addition, several representatives were assigned to serve in a consulting capacity. These included a Rad-Safe Adviser, a Safety Adviser, and a Classification Adviser. The Test Director's staff worked closely with members of each Test Group staff to insure mutual understanding and effective coordination.

The S-1 Staff was responsible for overall coordination of the following administrative support items: housing; office, laboratory, warehouse and control point space; vehicles; communications equipment; and miscellaneous support such as office furniture, Nevada Test Site (NTS) access, recreation and mail. Requirements for the above support items were collected from the Test Group Directors and other technical units requiring support. Allocations were made to the Test Group Directors from the supply made available to the Test Director by the Test Manager.

The S-3 Staff was responsible for coordinating the plans of the Test Group Directors and for publication of operation orders, shot schedules and general test information of use to all participants. This group supervised the planning and integration of dry runs, power runs and frequency checks. S-3 controlled check points and other operational details, including emergency evacuation of manned stations, during the period D-1 through D-Day for each shot. The Air Operations Officer was a member of this staff and represented the Test Director in all matters relating to air support.

The S-6 Staff was responsible for coordinating construction and contractor support for all participants in the designated test areas. This group was responsible for reviewing, for general coordination, all requests for contractor support, and worked closely with members of the Test Group staffs to insure that construction schedules were met.



TEST MANAGER
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TEST DIRECTOR
G W JOHNSON
ASSOCIATE TEST DIRECTOR
D. B SHUSTER
MILITARY ASSISTANT TO THE TEST DIRECTOR
WILLIAM S HUTCHINSON, JR.
FCWT
TEST GROUP DIRECTOR
R D COLEMAN
ALT. - A H HIGGS
G1 - EUGENE WILSON
G3 - L. P BISCHOFF
G4 - G P FORSYTH
G5 - E M THORNBURY
G6 - W A MCWERY
LASL
TEST GROUP DIRECTOR
Wm E OGLE
J1 - ARMAND KELLY
R C BEILER
S R WHITAKER
J2 - DUNCAN CURRY
B C LYON
J4 - HARRY ALLEN
R. J VAN GEMERT
J6 - R H CAMPBELL
R W NEWMAN
UCRL
TEST GROUP DIRECTOR
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ALT. - CHARLES E VIOLET
L1 - FLOYD W TRUITT
L3 - JOHN P FLYNN
L4 - DANIEL J MURPHY
L6 - ROBERT B PETRIE
CETG
TEST GROUP DIRECTOR
ROBERT L CORSBIE
FCDA ASST. - E R SAUNDERS
AEC ASST. - L J DEAL
C1 - S A ANTHONY - SC
J H SUTCH - ASC
J B WILLIAMSON - ASC
C3 - W W SCHOLBEL - SC
C4 - W T. ARMSTRONG - SC
J. H SUTCH - ASC
J B WILLIAMSON - ASC
C6 - E P. SCHMITT - SC
H J JENNINGS - ASC
SANDIA
TEST GROUP DIRECTOR
JAMES H SCOTT
ALT. - C E McCAMPBELL
A1 - A R VERARDO
A3 - JOHN W TANNER
A4 - A R VERARDO
A6 - N A LITTRELL
57
TEST GROUP DIRECTOR
JAMES D SHREVE
ALT. - Wm S HUTCHINSON, JR.
X1 - H V LEWIS
X3 - D G PALMER
X4 - H V LEWIS
X6 - D G PALMER
STAFF COORDINATOR
VERN DENTON
ALT. W D GIBBINS
S-1
ADMINISTRATIVE SERVICES
R A LUSK
ALT. RUTH W MURPHY
S-3
PLANNING
G P STOBIE
ALTS W B HOWERTON
NEIL HANSEN
AIR OPERATIONS
JOHN C TYSON
ALTS W A GUSTAFSON
DOUGLAS JOHNSON
S-6
CONSTRUCTION
C. M. PACIGALUPI
ALT. R W WERNER
RAD SAFE
W E NOLAN
ALT. GORDON JACKS
SAFETY
E L BRAWLEY
CLASSIFICATION
W H LAWRENCE (AEC)
ASSEMBLY & ARMING
E. L. JENKINS
R. BURTON
E. G & G SUPPORT
H. E GRIER
SANDIA SUPPORT
J H SCOTT

C. TEST GROUPS

As shown in the organization chart on page 16, the major scientific agencies and other users operating at the Test Site were organized under the Test Director into Test Groups. For Operation Plumbbob, Test Groups were established for LASL, UCRL, DOD, CETG, Sandia and a jointly sponsored group known as TG-57. Each Test Group was headed by a Test Group Director who coordinated the activities of his group at the Test Site. The Test Group Director was fully responsible at NTS for the internal administration of his group. He furnished the Test Director the support requirements necessary to effect tasks authorized by the Test Manager, provided to the Test Director shot scheduling and other information as requested, and was responsible to his home organization for insuring that his group obtained such support. The Test Group Director worked with other Test Group Directors and the Test Director to resolve conflicts of interest. He kept the Test Director advised of the technical readiness of his group, and assigned personnel necessary to conduct the shots under the sponsorship of his group. Agency participation in shots sponsored by other groups was arranged with the prior concurrence of the sponsoring Test Group Director.

D. SUPPORT GROUPS

Several Support Groups under the Test Director rendered necessary technical support to all the Test Groups. The EG&G Support Group provided timing signals to meet the principal requirements of the experimental programs. EG&G Support also supplied the firing signals for all devices being tested. The Assembly and Arming Support Group supervised a check-out of the complete firing system and made final connections of the device to the firing system as directed by the Test Director. In addition, this group was responsible for general coordination in handling and storing device components on receipt at NTS. The Sandia Support Group provided balloons, equipment and crews necessary for scheduled balloon shots and supervised the inflation and control of balloons.

E. RELATION TO OTHER GROUPS

As shown in the organization chart on page 18, the Test Director's Organization was one of the major elements of the larger Nevada Test Organization. The Nevada Test Organization was headed by the Test Manager who directed the planning for the Operation, and coordinated the activities of all groups involved in the conduct of the Operation.

The Test Manager was assisted, at staff level, by the Planning Board and the Advisory Panel. The Planning Board, consisting of representatives of the primary user organizations, had as its mission consideration of proposed nuclear weapons tests for the purpose of recommending to the Test Manager an overall plan for conduct of the test, firing schedules, and the assignment of firing areas to participants. The Advisory Panel was comprised of individuals with extensive weapons test experience and, as the name implies, advised the Test Manager (particulary with respect to safety of firing) of the ramifications of executing or delaying scheduled detonations.

Under the Test Manager, three groups, in addition to the Test Manager's own staff, functioned to conduct the operation. Primary of these was the Test Director's Organization discussed above. The other two groups reporting to the Test Manager were the AEC Support Group and the DOD Support Group. The AEC Support Group made available to the Test Participants the support required to conduct their scientific tests, except certain support required by the DOD. Under the AEC Support Group were such organizations as Holmes & Narver, Inc., the architect-engineer, and Reynolds Electrical & Engineering Co., Inc., the maintenance and construction contractor at NTS. The extent of DOD participation in the operation made it advisable to have a separate DOD Support Group which furnished transportation and supply support to the DOD Test Group.

NEVADA TEST ORGANIZATION

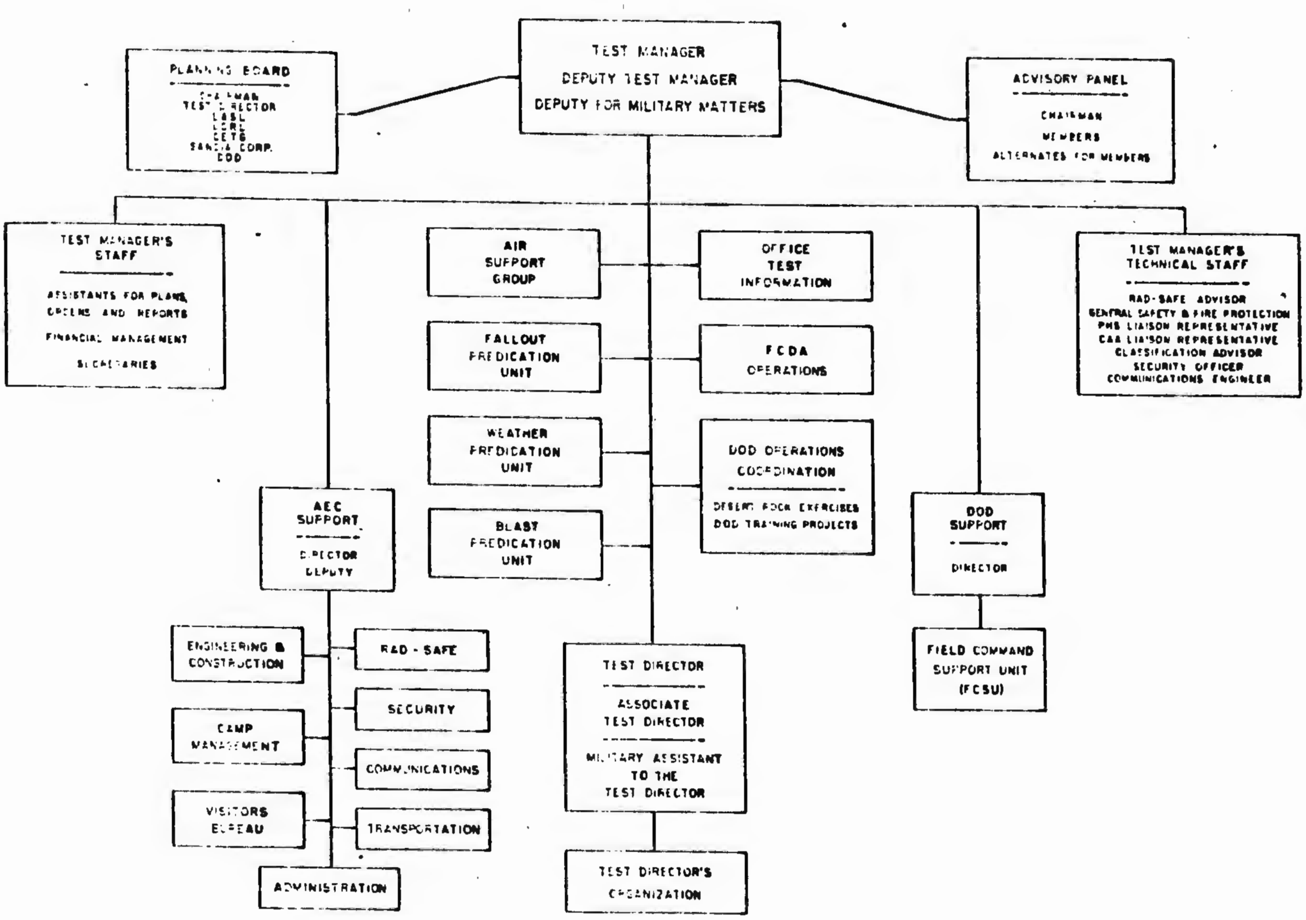

Figure 1-2. Nevada Test Organization.

CHAPTER II
SCIENTIFIC PROGRAM

A. INTRODUCTION

This chapter records, in summary form, the scientific aspects of the Operation, particularly in regard to the objectives, techniques, results, conclusions and recommendations stemming from the scientific program. The scope of the scientific program is best depicted by the Shot Schedule shown on page 22 which sets forth reference data pertinent to each of the shots.

Amplification of delays experienced are set forth in APPENDIX A.

Program and project participation in each of the shots is tabulated in APPENDIX B.

B. GENERAL PROBLEMS

The most difficult problems encountered were those brought about by schedule changes during the Operation, and the coordination of plans affected by such changes. With a group comprised of so many diverse interests as participate in a test series, late changes often introduced nearly insurmountable difficulties which reduced the efficiency of operation.

Another general problem facing operations at the Test Site was that of returning personnel to work in contaminated shot areas after a detonation. The problem of decontamination after an event was divided into two major parts:

1. Decontamination of areas that were contaminated by fallout.
2. Decontamination of areas that were contaminated by induced radiation.

The decontamination of areas that were contaminated by fallout followed the standard procedure of scraping approximately 2 to 6 inches of earth from the required working area, and depositing the scraped material in a contaminated dump. This procedure was very satisfactory and normally lowered the radiation levels in the scraped area by a factor of 5 to 8, depending upon the "shine" from the surrounding undisturbed areas.

The decontamination of areas that were contaminated by induced radiation presented a unique problem because of the fact that the contaminated layer was too deep to allow for the normal scraping as in partial fallout areas. To reduce this problem, the required working area was covered with about two feet of uncontaminated earth. This procedure normally reduced the radiation level by a factor of 3 to 5, depending upon the "shine" from the surrounding undisturbed areas and the depth of new fill. An experiment was conducted in which earth was mixed with a boron salt and spread over the working area prior to the event. This method shows promise of reducing induced contamination by a factor of from 5 to 10.

Some difficulty was experienced with events in which SS materials were exposed to the effects of nuclear explosions. Coordination between security and the monitor and project recovery personnel managed to solve most of this problem. In the future, however, it is recommended that any event in which SS material is to be exposed as an affect be reported in the Status Reports so that advance planning may be accomplished.

Some problems were experienced in the scheduling of dry runs by the various laboratories and experimenters. The existing signal system at the Test Site would not allow the operation of a single area in Yucca Flat for dry runs without sending the same signals to other Yucca Flat areas where the run was not desired. The signal system is being reviewed to increase its flexibility and to permit dry runs in any area, exclusive of the other areas.

Minor difficulty was experienced in internet interference between the various communication systems of the Test Groups. Although various means were tried to eliminate this interference, none was completely successful. Communication frequencies for future tests should be changed to eliminate this problem.

C. LOS ALAMOS SCIENTIFIC LABORATORY PROGRAM

The Los Alamos program at Operation Plumbbob had as its general purpose the testing of weapon models in various stages of development, and the conduct of experiments to increase knowledge of bomb design and performance. Several specific objectives can be distinguished, and although some of the test shots were aimed at several of them, most of the shots had a single objective.

One of the objectives was the proof-testing of new weapon models whose designs have become relatively firm. Models of similar, although not necessarily indentical, design had been tested in earlier operations. Design changes may still be made as a result of Plumbbob tests, but it is felt that performance of models of these designs is closely predictable.

Usually in conjunction with these proof tests, large-scale effects tests and other experiments were performed. These effects experiments were planned around the fairly certain expected yield of the bomb model used.

A second objective was safety testing. Models of recent design were detonated at one point and the nuclear performance was noted. Amounts of fissionable material in the models were varied greatly to bracket the maximum amount the system could contain and still be safe when detonated at one point.

A third objective was exploratory testing of models to clear up certain principles of design. Relation of yield (or other criterion of performance) to a design parameter (such as amount of fissionable material) was investigated over a wide range so that the optimal point could be found. The models used were usually

A fourth objective was the experimental determination of fundamental matters of design interest which could be achieved only by exploding a bomb.

In many shots for which the primary objective was proof-test or design-parameter test, it was possible to do additional experiments. In this way, work was done on the spectrum of neutrons, on the spatial origin of high-energy neutrons within the bomb, on the amount of gas burn, and on other items of design interest.

Comments on the separate shots follow:

Pages 21 and 22 deleted

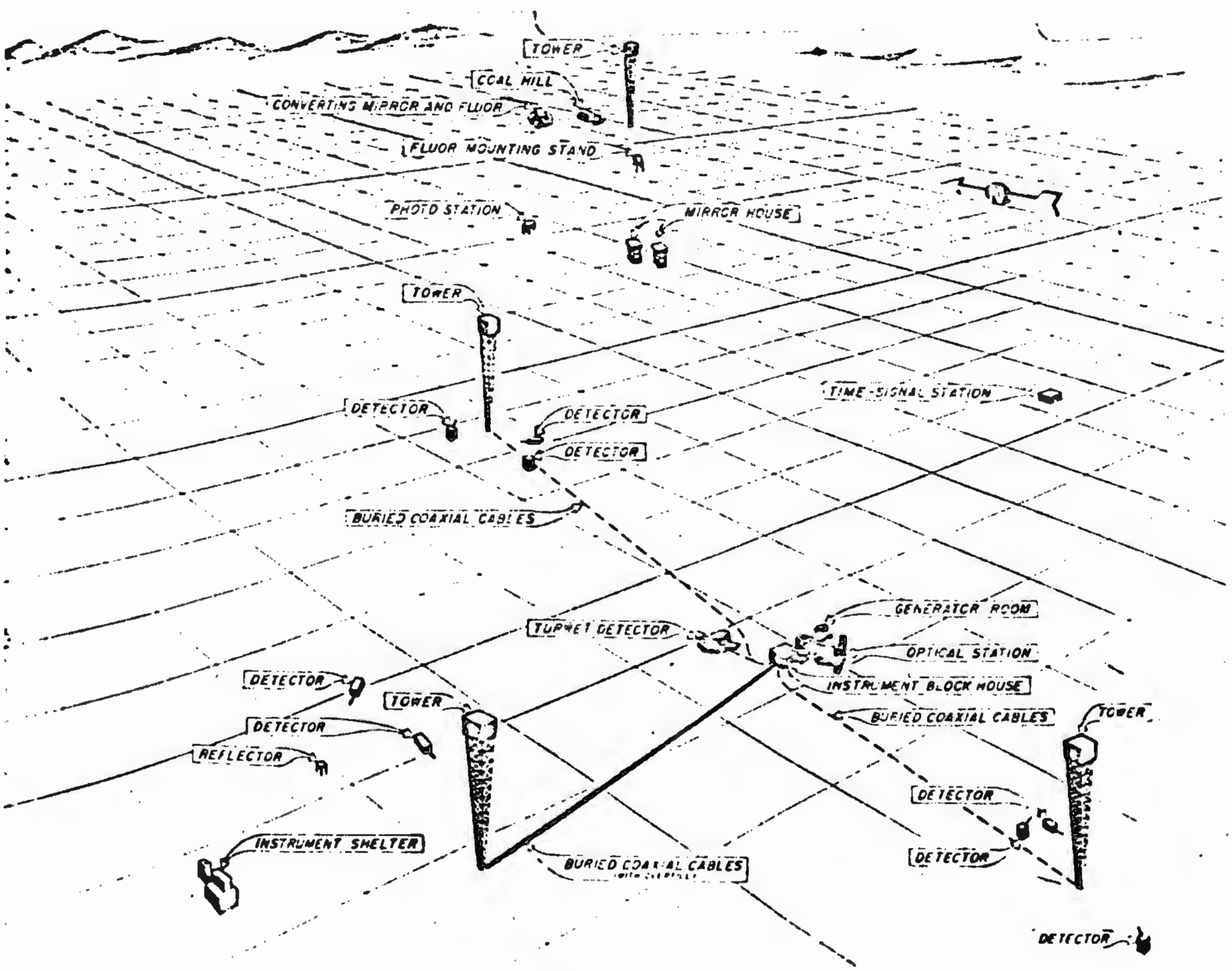

Figure 2-3. Area Two Schematic.

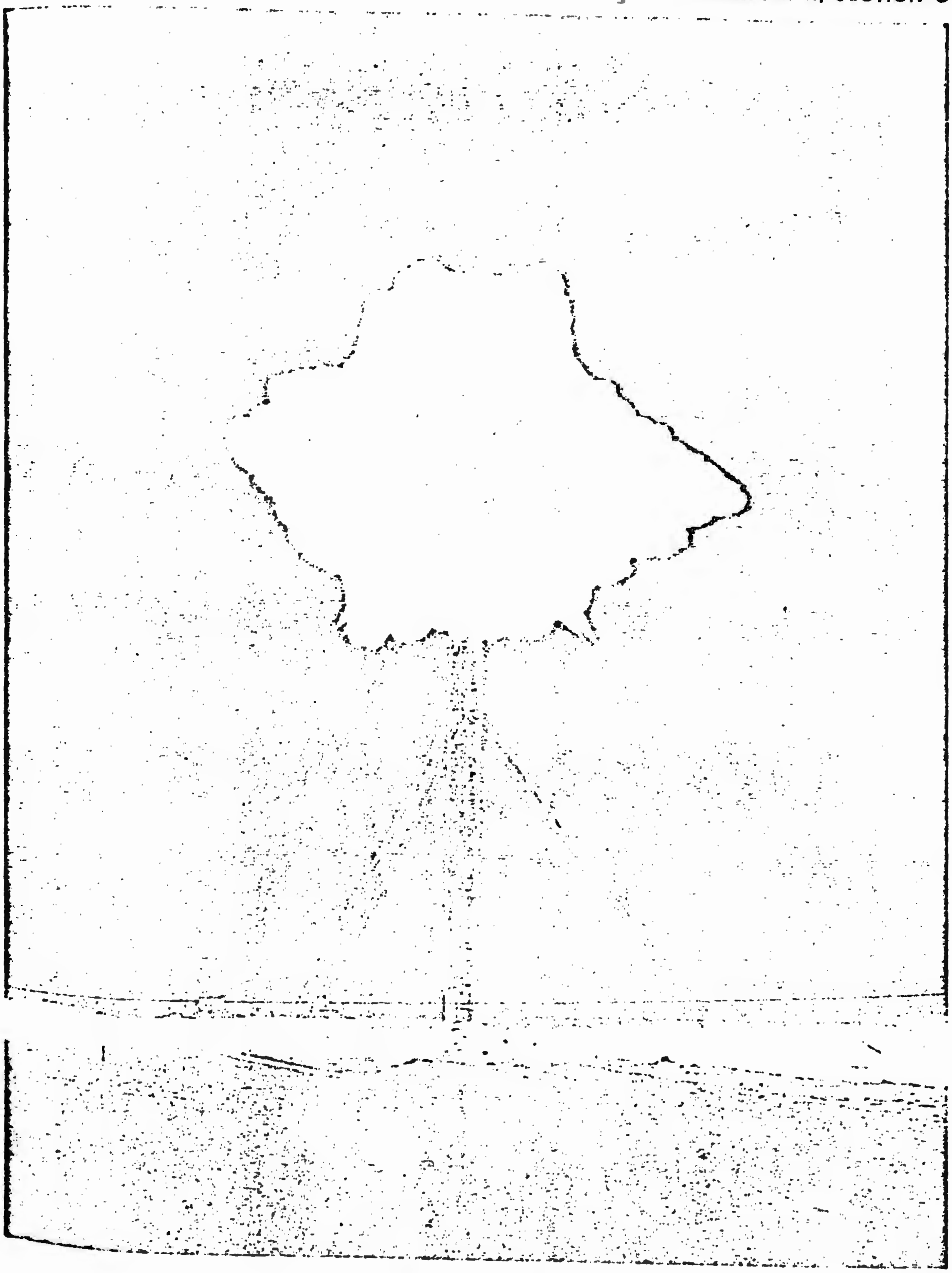

Figure 2-4. Shot Kepler - LASL.

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D. UNIVERSITY OF CALIFORNIA RADIATION LABORATORY PROGRAM

The devices tested by UCRL during Operation Plumbbob are logically divided into the two categories represented by the Laboratory's A and B Divisions. The test shots in each category, their results and the significant diagnostic experiments (Program 22) conducted with each are presented below:

A DIVISION

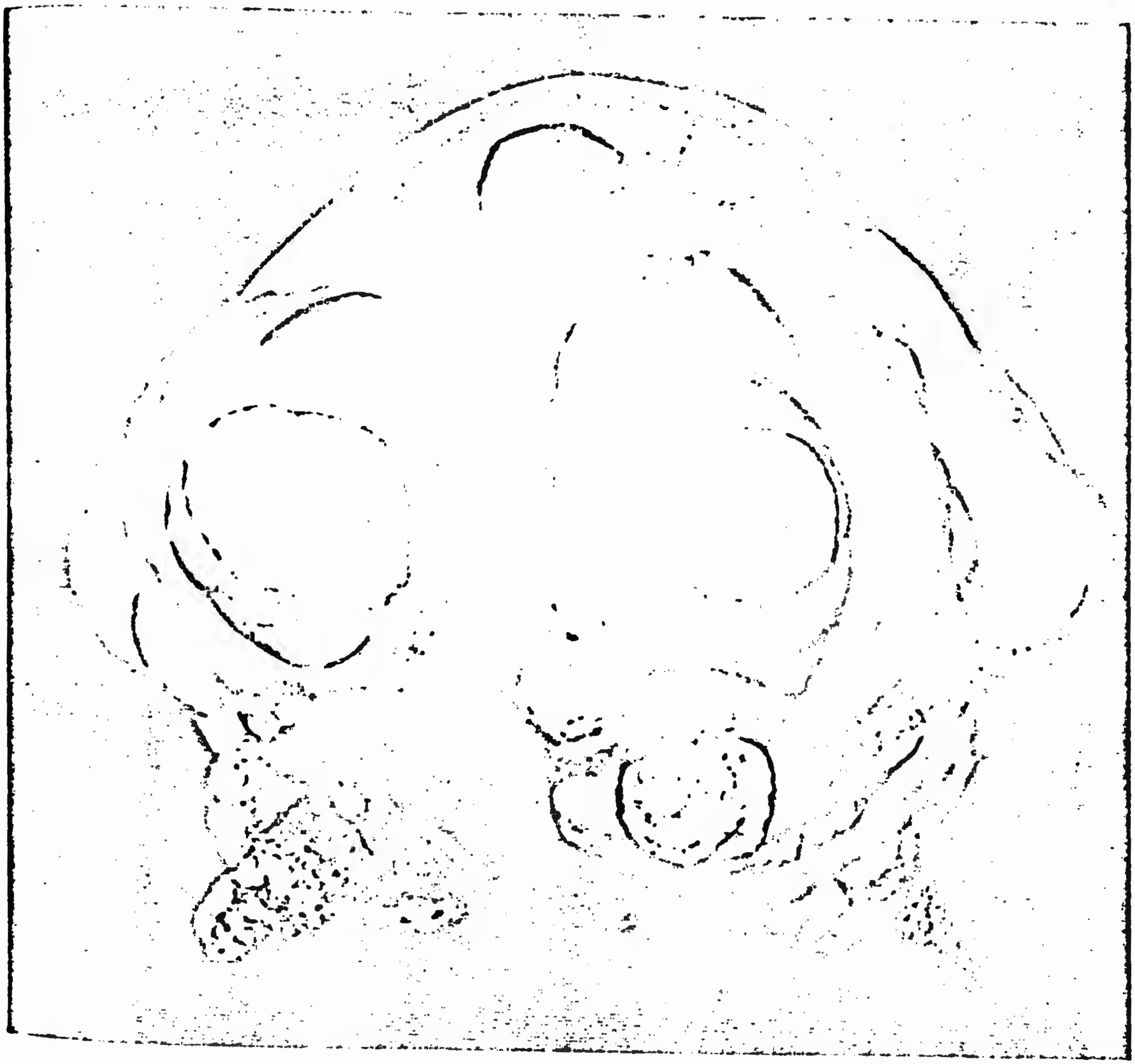


Figure 2-5. Fireball photograph - Shot Diablo—UCRL

pp 28 & 29 deleted

Figure 2-6. Trajectory of UCRL sampling rockets through atomic cloud. (White flecks are star trails.)

pg 28 & 29 deleted

PROGRAM 21

The complete preliminary results obtained by Program 21, plus the published bhangmeter and fireball data are presented below in tabular form:

SHOT	Fission Yield KT±5%	Bhangmeter KT±20%	Fireball Yield KT±5%	Remarks
Lassen	0.00047		0.00047	
Wilson	9.8	9.2	9.4	
Hood	70	70	70.6	
Diablo	16.5	13	23.8	
Owens	9.1	6.5	9.4	
Shasta	16.2	13.1	22.4	
Smoky	43	47	44.9	
Wheeler	0.197	0.16	0.153	
Whitney	17±10%	11.3	23.1	
Charleston	11	8	10.9	
Morgan	7.5	8	8	

In addition to the usual cloud sampling techniques, it was successfully demonstrated on several UCRL shots that rockets can be used to obtain particular debris samples. This technique will be explored further during Hardtack.

E. DEPARTMENT OF DEFENSE PROGRAM

The Weapons Effects Test Program of the Department of Defense (DOD) consisted of 44 projects. A large portion of the DOD effort was concentrated on shot Priscilla since this was a device of known yield and was designed as a DOD Weapons Effects shot. One of the primary objectives of the Weapons Effects Test Program was obtaining data on the loading and response of structures, and documenting blast and shock phenomena in the higher pressure regions — above 50 psi. The Smoky shot was of particular interest to the blast and shock program in the study of the effects of terrain on blast and shock phenomena. The studies of induced radio-

activity and of the electromagnetic signal generated by the detonation were made primarily on shots with relatively little or no shielding. The John shot, involving the air-to-air delivery of an MB-1 rocket by an F89D aircraft, provided information on nuclear and blast inputs to the delivery aircraft required to establish delivery criteria.

In general, the projects were successful in accomplishing the objectives of the DOD Weapons Effects Test Program.

PROGRAM ONE

(BLAST AND SHOCK MEASUREMENTS)

Advances in weapons systems have created the problem of designing structures and equipment to withstand overpressures above 50 psi. The collection of the air blast and ground shock data needed to enable practical design decisions for this high pressure region was one of the two primary objectives of the blast program. The second major objective was to obtain data on the effects of rough, hilly terrain on blast characteristics. The large amount of air blast data accumulated prior to this operation had been almost exclusively flat terrain data.

The specific objectives of the blast program were to; (1) obtain free-field measurements of overpressure, dynamic pressure, time of arrival and duration in the overpressure region between 50 psi and ground zero; (2) extend the data obtained under (1) out to the lower pressure regions (about 6 psi) in order to have continuity for a complete pressure-distance curve; (3) measure the variation with time, depth, and ground range of underground effects resulting from overpressures higher than 50 psi incident on the ground surface; (4) measure air-induced underground pressures on large size buried objects of different flexibilities in the high pressure region as a function of depth and ground range; (5) obtain measurements of overpressure, dynamic pressure, time of arrival, and positive phase duration along: (a) a flat terrain reference line, (b) one line of low rolling, rough terrain, (c) two lines crossing large hills of differing slope, and (d) an approximate line over rough mountainous terrain; (6) obtain measurements of the influence of terrain characteristics such as gullies, washes, mounds, etc. and also of the gross terrain features on damage to military equipment.

The main effort on air blast phenomena in high pressure regions was concentrated on shot Priscilla. The Stanford Research Institute (SRI) and the Ballistics Research Laboratories (BRL) were the principal test agencies. At ground ranges less than 2,000 feet, locations were selected to insure pressure-time records both before and after precursor formation and to determine the location of the start of the precursor (predicted at 600 feet). At ground ranges of 2,000 feet and beyond, locations were chosen to take advantage of towers left from the Teapot Operation. A new supersonic gage was used to measure dynamic pressure at 3-foot heights at distances from 450 to 2,500 feet while the old subsonic pitot-tube was used at ranges from 4,500 in to 1,050 feet. The overlap was for backup purpose and for comparison of gage types. Standard BRL and SRI ground baffles were used for overpressure measurements and were placed from ground zero out to a ground range of 6,000 feet. SRI also installed an array of blast switches for time-of-arrival measurements so that arrival time data from pressure-time records could be extended and refined.

Considerable air blast data at ground ranges as close as 350 feet were obtained. The highest overpressure measurement was 971 psi at 350 feet ground range and the highest dynamic pressure measurement (3 feet height) was 510 psi at 850 feet ground range. Unfortunately, electronic measurements at ground zero were lost presumably due to the induction signal produced by the explosion. The closest dynamic pressure measurement to ground zero was at 450 feet where 280 psi was recorded. The large drop from the maximum pressure of 510 psi at 850 feet to the 280 psi reading represents the first experimental evidence of the expected drop in dynamic pressure from the region of Mach to the region of regular reflection. The few possible comparisons of the supersonic-head gage with the subsonic pitot tube gage recording were poor, the new gage giving a much higher raw reading of dynamic pressure

Static and dynamic pressure gages were installed on 4 balloon shots and 5 tower shots at ranges which would document the complete precursor cycle. Strong precursors were formed on all balloon shots, but four of the five tower shots showed little evidence of a precursor, implying that precursor formation is inhibited by tower shielding.

Terrain effects studies were limited to shot Smoky. The ground zero was chosen so as to provide a variety of terrain in different directions. Five lines of instrumentation were installed as mentioned earlier in the objectives. BRL and SRI were again the responsible agencies so that the primery overpressure and dynamic pressure gages used were of the same type as those of shot Priscilla. BRL also installed pitch gages at a height of 3 feet on two of the lines since it was felt that pitch angles of flow over hilly terrain might vary markedly from the plane of the slope.

The data show that (1) measured pressure values on the flat (control) terrain agree with

predictions, (2) overpressures on front slopes of high ridges are higher than flat terrain pressures at corresponding distances while back slope pressures are lower, (3) overpressures on low, rolling terrain are higher than flat terrain pressures for like ground distances; dynamic pressures are lower, (4) dynamic pressures on front slopes of high ridges are lower than flat terrain pressures at corresponding distances and fall sharply below flat terrain pressures on back slopes, and (5) the wave forms on all front slopes have a smaller rise time than corresponding wave forms on the flat terrain line. Wave forms on the backsides of slopes are very nearly ideal. Wave forms on the low, rolling terrain line never did show a strong presursor.

There were 190 channels of instrumentation installed to document the ground shock studies of underground acceleration, stress, strain and displacement induced by the air blast wave from the Priscilla shot. Most of the instrumentation was concentrated at ground ranges of 650, 750, 850, 1050, and 1350 feet (overpressures of 300, 230, 160, 115, and 64 psi), and depths from the surface to 100 feet.

Measured values of acceleration agree with predictions between the surface and a depth of 10 feet, but remain constant (or increase) between 10 and 30 feet; below 30 feet, values again agree with predictions. The consistently high values between depths of 10 and 30 feet are believed to have been caused by inhomogeneities in the soil. A seismic survey made during the operation indicated that the soil between the surface and 100 feet was not uniform, and it is expected that a correlation can be made between the results of the seismic survey and the acceleration data. In addition to the free-field acceleration, data were also recorded by accelerometers mounted in the top and bottom of 3 concrete piles extending to a depth of 100 feet. The accelerations at both the surface and 100-foot levels in the piles were about the same as the free-field accelerations at the 100-foot level. All piles recorded about 5 g's at the top and bottom, while adjacent surface pads recorded 35 to 70 g's. Horizontal accelerations were lower than vertical acceleration at the surface by a factor of 2 to 5, but became equal or greater at depths below 30 feet.

Two types of stress instruments were used: SRI used standard Carlson stress gages and AFSWC used large (2-inch diameter) steel drums with flexible diaphragm ends to simulate buried structures. Diaphragms of five thicknesses (flexibilities) were used. The values recorded by the Carlson gages show a rapid attenuation of stress down to a depth of about 25 feet, and a rise (by a factor of 2) from 25 feet to 50 feet. It is believed that the records from the 50-foot gages are more realistic. The low stress values down to 25 feet are probably due to the difference in soil characteristics between the uniform backfill and the non-uniform surrounding soil. There are two results from the AFSWC drums which appear to be significant. First, the stress indicated by a diaphragm was influenced by its flexibility; the more flexible diaphragms recorded lower stress than stiffer diaphragms at the same location. The comparison of stress to diaphragm flexibility is expected to give an indication of the response of a structure to underground loading as a function of its flexibility. The second result was a large decrease in stress between the surface and a depth of two feet. There is no satisfactory explanation for this observation.

Eight out of ten strain records were lost or partially lost because of mechanical failure of the gages.

Vertical displacement produced by the blast wave was about 14 inches at an incident overpressure of 270 psi, 6 inches at 200 psi, 3 inches at 100 psi, and 2 inches at 60 psi.

A project was also included to study shock spectra. The equipment consisted simply of a canister containing ten single-degree-of-freedom reed gages. Each reed gage was adjusted for a different natural frequency of vibration. As the reed moves, an attached stylus marks displacement upon a record plate. Thus the maximum displacement for a particular frequency is recorded. The assembly could be mounted to either a vertical or horizontal position depending on the component of ground shock desired. Radial or transverse horizontal measurements were obtained by properly orienting the canister with respect to ground zero.

Canisters for measuring the three components of displacement were installed on five shots at locations with predicted overpressures of some 100 psi. The shots were chosen so as to provide a variety of soil conditions. The canisters were placed with their tops flush with the ground surface. Additional canisters were installed in one of the German shelters on shot Smoky. Only preliminary results are available at this time. Good records of maximum displacement as a function of frequency were obtained. Peak displacement measured was 3 inches at a frequency of 3 cps. Peak accelerations derived from displacement data showed the expected small accelerations at low frequencies and maximum accelerations (110 g largest measurement) at frequencies of about 100 cps. Velocity spectra derived showed that peak velocities occured at frequencies of 20 to 50 cps.

PROGRAM TWO

(NUCLEAR RADIATION STUDIES)

Program Two had 10 projects with the following objectives:

1. Neutron-Induced Soil Activity Studies (Projects 2.1, 2.2, 2.3, 2.4, and 2.5).
   - a. To investigate the gamma activity induced by neutrons in three types of American soils and in selected constituent soil elements.
   - b. To measure the flux and spectra of neutron radiation which gives rise to the measured induced activity.
2. Initial Nuclear Radiation Measurements (Projects 2.3, 2.5, 2.9, and 2.10).
   - a. To measure the neutron flux, spectra, and total neutron dose as a function of distance for weapons of potential tactical interest.
   - b. To measure initial gamma dose rate as a function of time and distance for several events.
   - c. To measure variation of neutron and gamma dose, and gamma dose rate with time as a function of altitude and distance in order to determine the effect of the air-earth interface.
   - d. To measure the nuclear radiation doses sustained by aircraft crews in delivery of an MB-1 air to air missile.
3. Radio Wave Attenuation Studies (Project 2.7).
   - a. To proof-test nuclear radiation measurement instrumentation intended for use on Operation Hardtack.
   - b. To investigate the attenuation of electromagnetic waves by the ionized sphere generated by an atomic detonation.
4. Shielding Studies (Project 2.4).
   - a. To measure the gamma and neutron shielding characteristics of foxholes, machine gun emplacements, personnel shelter units, M-48 tanks, ONTOS vehicles, hemispheres of new and standard armor materials and Program 3 structures.
5. Instrument Evaluation (Projects 2.6 and 2.8).
   - a. To proof-test a newly developed tactical neutron dosimeter system.
   - b. To perform a field operational evaluation of the IM-93 beta-gamma survey meter.
   - c. To evaluate the performance of specially shielded DT-60/PD and IM-107/PD dosimeters and standard AN/PDR-43 and AN/PDR-44 survey meters in measurement of equivalent "deep" body dose and dose rate, respectively.

The results of the induced activity studies showed that neutron-induced soil activity is a definite tactical hazard at early times. The primary isotopes which gave rise to this hazard were found to be Na^{24}, Mn^{56} and Al^{28}. The induced activity was found to be generated primarily by thermal neutrons, although epithermal and even fast neutron contribute to the activation. The effect of increased moisture was to increase the intensity of the fields, although the effect is not as critical as had been expected.

Using the data obtained in these experiments, it is indicated that a foot soldier crossing the ground zero area of a weapon of the Owens type detonated at 500 feet over Nevada or Chester soil at H plus 1 hour would accrue no more than 200 R. If the crossing were delayed to H plus 10 hours, a dose of about 40 R would be sustained. For Dade soil, which has a low Mn and Na content, traversing the induced field as early as H plus 1 hour would not result in any dose of military significance.

The results of the initial radiation measurements indicated that for shots Wilson and Owens the measured neutron dose exceeded that predicted for high neutron flux weapons by by factors of 2.5 and 4 respectively. For Priscilla the measured dose was lower than the predicted by a factor of 2.5, while for Franklin the measured and predicted doses were in very close agreement. The Smoky results are presently inconclusive. The heavy fallout resulting from this event prevented recovery of the instrumentation for several days and therefore considerable data were lost.

As a result of the initial gamma measurements, it was learned that the total gamma dose gradually increases with height above ground to reach a value 30 percent greater than the corresponding ground measurement at an altitude of 400 feet over the first 5-second interval for which data were obtained. There is evidence of change of gamma mean free path with time.

The air-to-air missile delivery results indicate that an MB-1 rocket can be fired from an F89D interceptor aircraft at an altitude of

19,000 feet MSL with a gamma dose to the crew of less than 3 R. The neutron dose was below the lower limit of detection for the foil and chemical detectors, however the human counter results indicate a neutron exposure of approximately 3 rep. The flight pattern of the delivery aircraft has a marked effect on the gamma exposure received, and in particular, the exposure received during the interval of closest approach to the fireball was found to be a significant portion of the total dose.

The detectors and detector circuits proposed for electromagnetic wave attenuation studies on Hardtack performed properly in the electromagnetic field, when properly shielded. The neutron sensitivity of the detectors was not adequate but can be achieved by appropriate modifications. It was found that instantaneous telemetering of data was not feasible, and that recording and re-transmission of the data will be required.

The data obtained on the various parameters effecting attenuation of radio waves is not readily interpretable, and further evaluation of the data is required before its significance can be determined. Radio waves passing through the fireball were attenuated by more than 50 db. The duration of the anomalous condition was 6 seconds. Radar reflection from the fireball indicated that this effect is small enough to be considered negligible, the equivalent reflecting area being less than the reflection area of a sphere 0.8 meters in radius.

Results of the shielding studies showed that the buried conduits of Project 3.2 and the underground steel-arch shelters of 3.3 provided adequate protection against initial radiation. The underground concrete arch shelters of 3.1, on the other hand, did not provide satisfactory shielding due to scattering through the entrance ways.

The neutron dosimeter evaluation indicated that the system tested did not measure neutron dose satisfactorily, and that, in addition, ion chamber type instruments do not measure gamma dose accurately under conditions of high neutron flux.

The IM-123 evaluation, although impaired by lack of beta data, indicates the instrument is promising, however, further development is required.

The shielded IM-107 dosimeters were found to give good correlation with depth dose, while the DT-60's did not. In the case of the DT-60's and also for the AN/PDR-43 and AN/PDR-44, more shielding appears to be required if equivalent depth dose or dose rates are to be measured. Results were similar for both induced and fallout residual fields.

PROGRAM THREE

(EFFECTS ON STRUCTURES AND EQUIPMENT)

Program 3 consisted of eight projects and had a primary objective of obtaining loading and response data on various types of above and below ground structures in the overpressure region above 50 psi. The second major objective was to proof test various underground structures on a "go-no-go" basis to determine their ability to provide Class I (100 psi) and Class II (50 psi) protection as prescribed in the current DOD protective construction policy. The third major objective was to obtain any loading and response information from existing structures, constructed for past tests in the Frenchman Flat area.

As a related objective, these same structures were utilized by projects of Program 2 for studies of gamma and neutron radiation shielding within the structures. Two DOD agencies, Ballistics Research Laboratories, (BRL) and Armour Research Foundation (ARF), of Program 3 provided all structures blast loading and response instrumentation for the DOD as well as CETG structures projects. Also, the DOD dome and arch Project 3.6 and related CETG dome Project 30.1 were coordinated and mutually supported.

Participation of Program 3 was concentrated on the Priscilla shot. A total of 25 newly constructed, major, full-scale structures, extensively instrumented, were tested. In addition, several more minor full-scale structures and several more structures existing from previous operations also were tested.

The eight projects included in Program 3 were in three general groups:

1. Loading and response of underground structures in the high-pressure region.
2. Loading and response of above-ground structures in the high-pressure region.
3. Loading and response of various existing structures primarily in the low and moderate pressure regions.

The projects were very successful in achieving the objectives of the program, and have made a significant contribution to the blast and shock structural loading and response information available for the higher pressure regions.

The numerous underground structures tested sustained less damage than predicted, from which it is concluded that the design assumptions upon which such underground structures had been planned and analyzed, were more conservative than necessary for the size spans tested. It was also shown, confirming theory, that underground arch-type shelters are structurally

a most efficient type to withstand high overpressures, and this type can be readily constructed to withstand overpressures up to at least 200 psi. It is further concluded that DOD Class I and Class II personnel protection can be readily obtained, for 40 kiloton size weapons, by at least any of the following three types and sizes of underground structures tested: (1) the underground, commercially available, 8-foot diameter corrugated steel or concrete conduits; (2) the underground, 16-foot span reinforced concrete arch structures; and (3) the partially underground, 25-foot span, rib-strengthened, modified standard stock, corrugated steel arch structures. For the above structures, the results indicate that a minimum of about 5 feet of earth cover is required to provide sufficient radiation shielding protection.

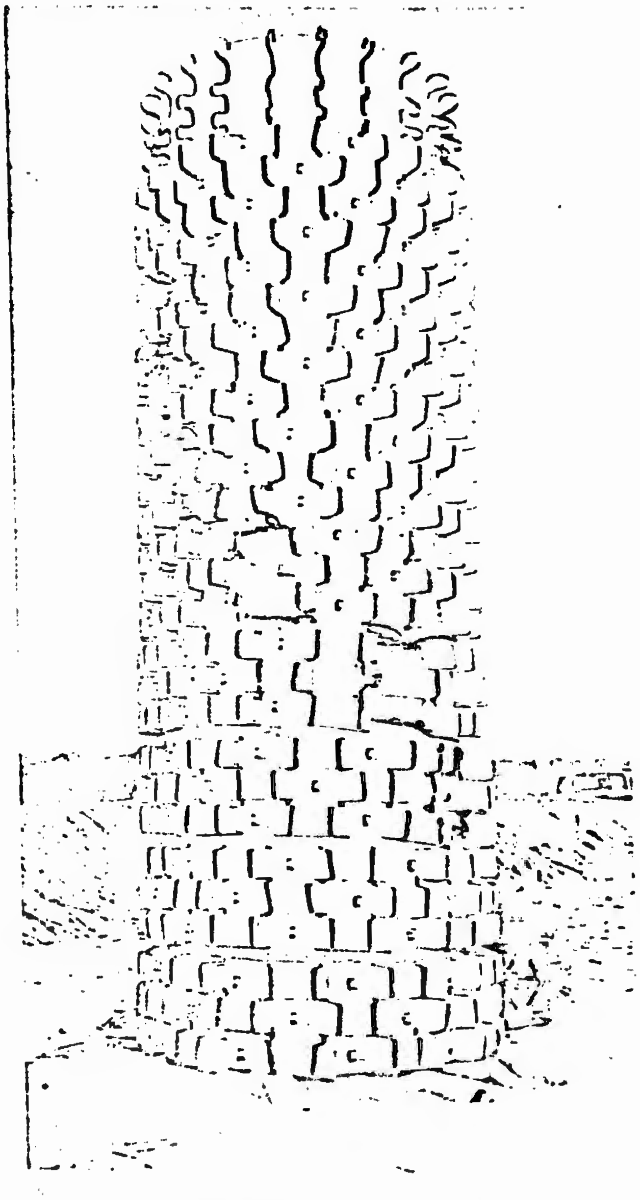


Figure 2-7. Frangibility test. Reinforced concrete pipe surrounded by gin bottles.

The above ground dome and arch structures tested sustained somewhat greater damage than expected. For the domes this was probably because the reflected pressure loadings on the dome curved surfaces were in excess of predictions; for the arches the reflected pressure loadings were slightly less than perdicted. Considerable analysis of the data obtained is required before a comparison with proposed analytical methods and full-scale test results can be made known. However, the tests on domes and arches generally confirms theory and model shock tube data which indicate that for above-ground protective structures the curved-surface dome and arch-type structures are structurally the most efficient type for use in higher overpressure regions, and that such structures can be constructed to withstand overpressures up to at least 70 psi.

PROGRAM FOUR

(BIO-MEDICAL EFFECTS)

The effort of Program 4, consisting of three projects, was designed to: (1) furnish information on the effects of nuclear weapons on a large biological specimen (swine); (2) evaluate the eye protection afforded by an electromechanical shutter; and (3) evaluate the casualty effect of missiles translated by a nuclear detonation.

To evaluate the biological effect of nuclear weapons some twelve hundred swine were systematically exposed to the effects of shots Franklin, Wilson and Priscilla. Eye protective devices were evaluated by exposing rabbits and human volunteers to the flash effects of Boltzmann, Wilson, Priscilla, Hood, and Diablo. The major missile information was obtained from the blast effects of shots Priscilla and Smoky.

Neutron measurements were made using the system of Hurst, with gold, sulphur, neptunium and plutonium detectors. Gamma-ray measurements were made by the use of the chemical dosimeter system developed by Sigoloff.

Preliminary radiation levels measured in air for the unshielded line of exposure on shot Wilson indicate that the LD/50/30 of pigs is about 500 rep gamma rays plus neutrons. This LD/50/30 dosage compares favorably with information obtained from project laboratory experiments, but is considerably higher than the LD/50 of 230 R obtained during Operation Greenhouse. Dosimeters were sutured to the posterior gastric wall and also placed in the vagina of some animals to obtain depth dosage. The results of this dosimetry are not yet available. Midline dosimetry combined with air dosimetry should result in a correlation between physical dosimetry and depth-dose response.

The main effort was on shot Priscilla where some 710 swine were in the open and subjected to the effects of the detonation. Because of the

small number of desired type wounds, the evaluation of the medical and surgical treatment did not produce conclusive results. There were some serious missile injuries. Some 60 odd animals were evacuated from the exposure stations with either interperitoneal contents extended or a diagnosed penetrating abdominal or thoraco-abdominal wound. However, because of heat, dust, and cannibalization of seriously wounded animals by those wounded less seriously, only 19 of the expected 100 animals were evacuated from the triage station for the evaluation of medical and surgical treatment study. Under the conditions of the experiment, animals suffering missile wounds from glass, in most instances, received lethal doses of irradiation. Many of the animals received serious thermal burns. There was an inverse association between degree of burn and survival time of the exposed animals.

Two groups of nine animals each exposed to superlethal dosages of 1440 rep and 1270 rep, respectively, of body radiation on shot Wilson and 34 animals exposed on shot Priscilla to lesser dosages of radiation, were given intravenous transfusions of a mixture of cells from spleen and bone marrow and clinical response observed. The average survival time of the irradiated animals that received transfusions of splenic and marrow cells was no longer than that of other animals exposed at the same time to comparable levels of radiation.. All post mortems of the animals that received the transfusion gave no evidence of regeneration of the bone marrow.

Peripheral white blood count as obtained by the standard chamber counter method correlated well with the amount of radiation the animals received and gave indication of the clinical course of the animals in that when the peripheral white blood count fell to 2500 or less, death of the animal followed within 24 hours. The technique of pin-head leucocyte count was evaluated, and it was found that for a white blood count of about 15,000 there was a tendency for the technician to under-estimate the true count while in ranges below 10,000 there was a better correlation with the standard count. The technique of pin-head white blood count appears to be acceptable for radiation victims.

Five animals placed in machine gun type field fortifications near shot Priscilla ground zero survived the blast effects but four of the animals later succumbed to the radiation and thermal effects. Two animals placed in the foxholes 36 inches deep at 2730 feet and 3000 feet from ground zero survived the blast and thermal effects, but death occurred due to radiation exposure at 6 hours and 91 hours respectively after exposure. Four anesthetized animals placed in crew positions of a tank 1,800 feet from ground zero on shot Wilson were dead upon recovery. Because of the extremely high radiation dosage there is no possibility that a human tank crew could survive a similar experience.

An analysis in considerably more detail of the data on the animals exposed close in to ground zero will give additional information regarding the death of exposed animals. However, the clearcut conclusions from these findings will remain; namely, that for a large biological specimen in the open, within the precursor from a nuclear weapon, the primary cause of death is mechanical injury to the organisms due to translation, and nearly 100 percent are killed instantly. Outside the precursor, temporary survival may be expected in the open, barring total missile injury, but the radiation levels at these ranges are so great that early death will invariably ensue. Close-in foxholes may provide sufficient protection to prevent total injury from blast and burn, but the radiation shielding is inadequate, and a lethal dose of radiation will ultimately be the cause of death, with slightly longer survival time.

In the swine exposed to the nuclear device the wounds caused by flying glass fragments did not significantly influence overall mortality. In a range where the missiles produced a considerable number of wounds, irradiation was superlethal.

As a result of the random exposure of the animals over a wide range of distance from ground zero, many combinations of radiation, thermal and mechanical injury were observed. If it is feasible to extrapolate these results to man, considerable knowledge pertaining to weapons effects on military personnel in the field should be available following the analysis.

The eye protection device tested was a high speed electromechanical shutter. The closing time of the shutter after a flash detector senses an unusual illumination is approximately ½ msec. There were two exposure stations, one ground station and the other in a C-47 aircraft. The stations were located at a distance where the light permitted through the open shutter would not exceed the chorioretinal burn threshold.

The shutter gave complete protection from chorioretinal burns and flashblindness. Human volunteers observing the detonation through the operative shutters had no measurable recovery time and no scotoma, while unprotected rabbits exposed to the bomb flash received minimal chorioretinal burns.

Volunteers behind inoperative shutters suffered flashblindness with a definite recovery period. The subjects required 10 and 12 seconds respectively to recover useful vision, which would still permit them to read aircraft instruments.

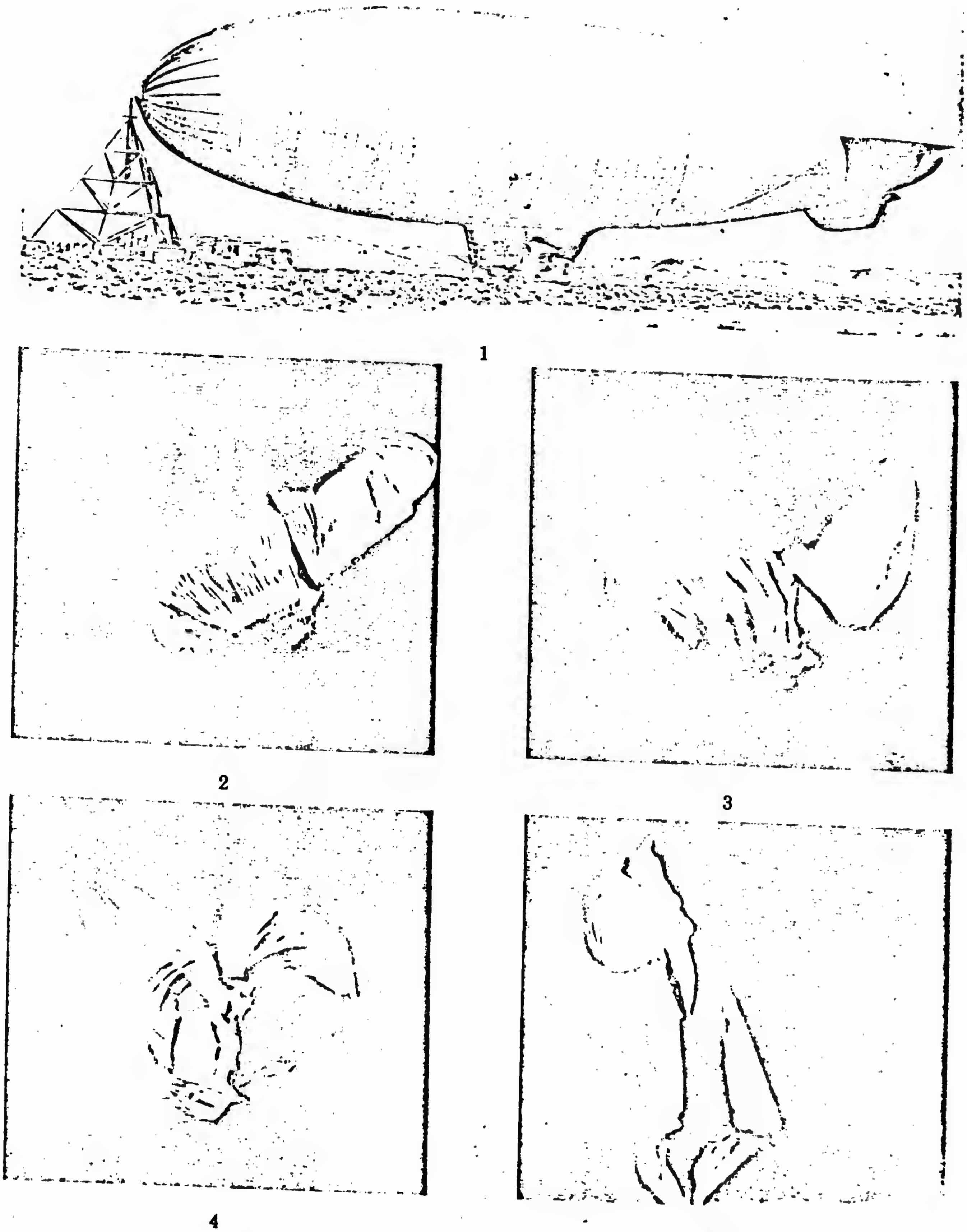


Figure 2-8. Destruction of ZSG-3 airship — Shot Stokes.

It can be conclusively stated that the electromechanical shutters tested during Operation Plumbbob and under the conditions of this test provided protection against flashblindness and chorioretinal burns and are sufficiently developed to be incorporated into a goggle for service testing.

The project to evaluate the casualty effect of missiles translated by a nuclear detonation was carried out by the Lovelace Foundation for Medical Research under the joint sponsorship of the DOD and Civil Effects Test Groups. The project was under the administrative control of the CETG and the details will be reported as CETG Project 33.2 (ITR 1468).

PROGRAM FIVE

(EFFECTS ON AIRCRAFT STRUCTURES)

The objectives of the aircraft effects studies were to extend the scope of presently available data in line with specific service requirements. Definition of aircraft safe delivery criteria for nuclear weapons was fundamental to all projects. Blast inputs, and aircraft skin temperature rise from known thermal inputs can be predicted within reasonable limits. However, the dynamic gust loads resulting from blast, and the thermal inputs have been predicted with much less confidence.

Two of the aircraft effects projects involved unconventional aircraft, an HSS-1 helicopter and a ZSG-3 airship. Both of these projects were concerned with the problem of delivering nuclear anti-submarine warefare weapons.

Two of the projects involved Naval aircraft types, the FJ4 and the A4D-1. Both aircraft were of small dimensions and short structural response times, one a swept wing and the other a modified delta. The FJ4 had honeycomb control surfaces susceptable to temperature effects. The basic field of interest concerned the air-to-ground delivery.

The remaining project involved an Air Force F89D and was concerned with the critical air-to-air delivery program. Particular emphasis was placed upon participation in the John shot where the aircraft recorded thermal and blast inputs and responses, and nuclear input information. This participation also provided the first data obtained with which to examine the effects of gust loads imposed on maneuvering loads.

Thermal data obtained during the operation was of low magnitude, particularly for helicopter and blimp projects where no substantial inputs were measured. F89 thermal inputs were also insignificant.

Blast responses included the crushing effects of overpressure and the effects due to the gust velocity. The prediction methods involved indicated that the Navy predictions based upon an experimentally derived curve and utilizing modified Sachs scaling were slightly unconservative. The F89 project, utilizing the M-Problem curve and modified alpha scaling was found to be slightly conservative.

Time of shock arrival predictions were generally excellent. Reflected shock predictions, important in calculated gust loads, were fair for time of shock arrival but were inconclusive in predicting the magnitude of the second shock overpressure.

The helicopter was limited in its participations due to the comparatively low overpressure which the fuselage structure could withstand. Therefore, for these tests, temporary reinforcing was added to the tail cone structure. Overpressure levels up to 1.07 psi were received with this reinforcing added. Later in the tests the reinforcing was removed and levels up to 0.43 psi were recorded. Correlation of stress information was not attempted in the field.

For the airship project, results of shock wave-induced loading are inconclusive pending detailed analysis of film data. Preliminary review indicates the possibility of high or fluctuating pressures existing in the nose section of the envelope during shock passage particularly around the aft section of the forward ballonets. From the failures which occured, it appears that the envelope and possibly ballonets are the weak links in the system. Car suspension systems, tail structures, and the car appear to possess sufficient strength under the test conditions.

Results of initial shot participations by the FJ4 aircraft showed discrepancies in the analytical solutions used to predict structural loads. Empirical corrections were made and subsequent correlation was good. Wing pressure survey information was also obtained by this project utilizing chordwise pressure pickups. This project also obtained pressure survey information on the wing which may lead to analysis of the diffraction loading. The diffraction load, caused by the impact pressure of the shock wave at high angles of incidence had been considered unimportant for aircraft employed in past tests due to the comparatively long structural response time. However, it was included in the analysis and appeared to contribute a significant portion of the theoretical loading on the A4D and F89. The FJ4 participation had been planned for such low incidence angles that diffraction loads were not considered significant.

Gust loading predictions for the F89 during the tests had good correlation. However, the dynamic responses were found to be greater than those predicted analytically in the aircraft capabilities study. Diffraction loading was found

to be negligible, probably due to a longer response time than predicted in the analysis.

In general, the preliminary field analysis of data indicate that the objectives of the various aircraft studies were successfully met except for the airship project where further detailed analysis is required before adequate conclusions can be drawn.

The preliminary analysis of test data indicated that the crushing effects of overpressure will be limiting for the HSS-1 helicopter. Sufficient data were obtained to define these limits for the configuration tested. The delivery capability for nuclear anti-submarine weapons will not be fully defined, however, until sufficient information is available to accurately predict the free air effects field for underwater detonations.

Under the conditions of the tests undergone by the ZSG-3 airship, the car structure and suspension system appeared to be satisfactory strength-wise, but tail assembly movable surface stops may receive damage from shock wave forces on the control surfaces. For the free-flight conditions, the envelope and ballonet response to shock inputs appeared to be the critical element in the airship system. However, a detailed analysis of response data is necessary before final limiting criteria can be established.

The critical response of the FJ4 structure was determined to be bending at Wing Station 17.5. Good correlation was obtained between measured and analytical structural data for low yield weapons. Methods for predicting thermal inputs were not satisfactory. However, predictions of maximum temperature rise based upon measured inputs gave good correlation.

Sufficient data were obtained for the purpose of confirming the delivery capability of the A4D-1 airplane for low-yield weapons. Wing pressure data were collected for the preliminary investigation and analysis of the diffraction loading mechanism.

The dynamic response of the F89 to the blast associated with a nuclear detonation produced higher wing loads than predicted analytically in the capability study. Therefore, the delivery techniques specified in this study are unconservative. For the conditions tested, the significant F89 structural loads resulted only from the gust associated with the shock wave. Thermal and diffraction effects were so small as to be unimportant. Incremental dynamic loads were not affected by the magnitude of maneuvering loads existing on the structure at shock arrival.

PROGRAM SIX

(TESTS OF SERVICE EQUIPMENT AND MATERIALS)

Program 6 consisted of five projects: (1) a minefield clearance study; (2) a project to measure the magnetic field from a nuclear detonation; (3) an investigation of the effects of a nuclear cloud on the propagation of radio and radar signals; (4) a project involving the long range detection and location of nuclear detonations; and (5) a study of the radiation effects on guided missile components, materials, and systems.

In the mine clearance study, the principal objective was to investigate the behavior of pressure actuated anti-tank mines under blast loading from a nuclear detonation. Specifically, it was desired to determine the reliability of a specially developed method for predicting the probability of mine actuation under blast effects of a nuclear weapon; to study the effects of burial depth on mine actuation; to ascertain the effect of sympathetic actuation on the extent of mine clearance, and to determine the effects of changes in the shape of the overpressure pulse on mine response. Secondary objectives were to test the vulnerability of three types of influence anti-tank mine fuzes to a nuclear detonation, and to determine the ground contamination pattern of an E-5 chemical land mine detonated by nuclear blast effects.

The mine clearance study was conducted on shot Priscilla. Live and inert versions of fifteen types of United States, NATO, and other foreign anti-tank mines were exposed at predicted overpressures to obtain 90, 50, and 10 percent actuations. To study the effect of buried depth and the effects of changes in the shape of the pressure pulse, the US Universal Indicator Mine was exposed in the region from 5 to 60 psi at burial depths from 0 to 36 inches. The vulnerability of the three influence type mine fuzes was tested by exposing samples at predicted overpressures of 60, 10, and 5 psi. Data on the contamination pattern of the chemical mines were taken at 8 psi.

Preliminary examination of the data obtained indicates: (1) that the method used to predict the probability of mine actuation is reasonably accurate; (2) that sympathetic actuation extends mine clearance under nuclear blast effects; (3) that mine response under nuclear blast effects increases with burial depth to between 6 and 9 inches, and then decreases at greater depths; (4) that as the shape of the pressure pulse changes from a relatively slow rising front in the precursor region to a fast rising front beyond that region the mine response tends to increase; and (5) that the three

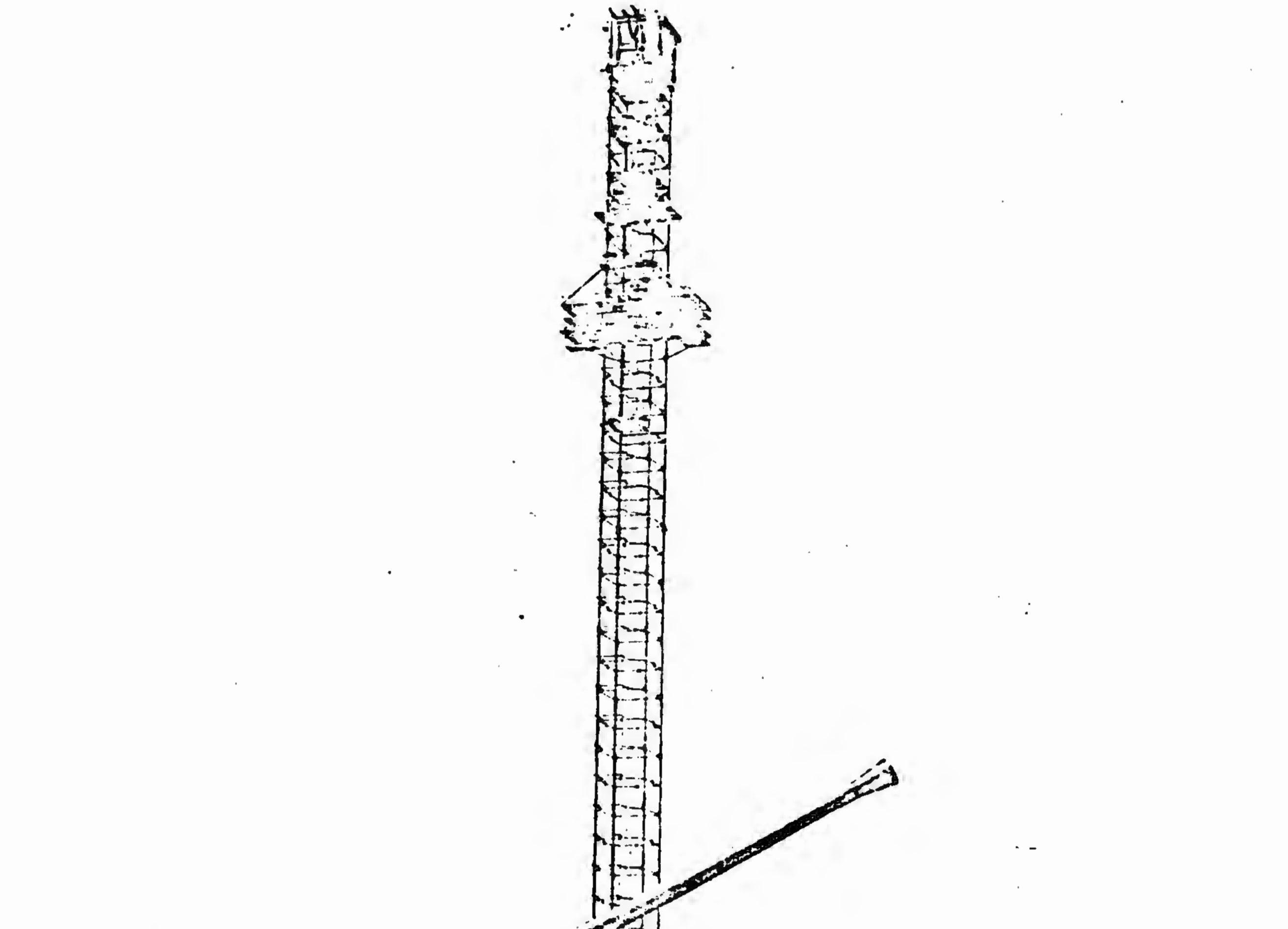


Figure 2-9. Effects test on service equipment.

influence type fuzes tested appear to be relatively invulnerable to a nuclear detonation.

In the project to measure electromagnetic effects, the principal objective was to measure in the near field region the magnetic component of the electromagnetic pulse emitted from a nuclear detonation. Specifically it was desired to obtain a time record of various spatial components of the magnetic field at several distances from ground zero with the purpose of: (1) ascertaining the effects of this phenomenon on magnetic influence mine fuzes, and (2) of investigating the possibility of using the early arrival of these phenomena to temporarily neutralize mine fuzes that would otherwise detonate on the late arrival of other effects. Measurements were taken on shots Lassen, Wilson, Priscilla, Hood, Diablo and Owens. Two to five measuring stations were established on each shot at ranges from 650 to 14,400 feet from ground zero. Excellent records of the azimuthal, radial and vertical components of the magnetic field in the frequency band up to 200 kc were obtained.

Preliminary observations indicate: (1) the largest component of the magnetic field lies in the azimuthal direction; (2) strong components, which do not resemble the azimuthal component and possibly have a different origin, exist in the radial and vertical directions; (3) the signal strength varies inversely at least as the square of the distance from the detonation and possibly as the cube; (4) the field is reduced to below an order of magnitude of the peak field strength in less than 100 microseconds with weaker signals persisting in some cases for several milliseconds.

In the investigation of the effects of a nuclear cloud on the propagation of radio and radar signals, the objective was to measure the attenuation of frequencies in the region from 4 mc to 9245 mc caused by their propagation through the ionized environment of a nuclear cloud. With the measurements obtained, it was planned to calculate the rate of electron removal within the cloud.

Measurements were made at approximately 4 mc, 20 mc, 160 mc, 960 mc, 3100 mc and 9200 mc by transmitting these frequencies from an aircraft flying a course so as to direct the energy through the cloud to a set of ground-based receivers. The output of the receivers was measured and compared with pre-shot calibration data to determine attenuation.

Measurements were made on Franklin, Lassen, and Wilson. No attenuation of any of the test frequencies occurred as a consequence of passage through the clouds.

In addition to taking attenuation measurements, an X-band radar was used to skin track a Navy FJ-4 aircraft screened by the nuclear cloud of Priscilla. Tracking was performed from H hour to H+6 minutes with the cloud interposed at about H+3 minutes and H+5 minutes. No reduction in the strength of the signal return was noted throughout this period.

To fulfill Air Force requirements for an "Atomic Strike Recording System," the Air Force Cambridge Research Center (AFCRC), through project 6.4, had the mission of continuing the investigation of a system that will indirectly detect and locate atomic strikes. The specific objectives included a study of the accuracy and reliability of the system as a function of distance and to investigate methods to isolate the bomb pulse from transients.

During Plumbbob three nets were operated—one at Albuquerque, 550 miles from the test site; another at Vale, Oregon, at 480 miles; and the third at Rapid City, a distance of 830 miles. Forty lines-of-position were obtained. The average error was 0.5 nautical miles in Albuquerque net, 0.4 nautical miles in the Vale net, and 0.8 nautical miles in the Rapid City net. These lines-of-position gave fixes having an average error of 0.8 nautical miles. In general, the times of detonation was established with an error of less than 10 milliseconds.

Lightning transient information was collected for approximately 10 hours throughout the test series at times of maximum thunderstorm activity. It was found there was no consistant patterns peculiar to the wave forms, field intensities, or pulse durations of these transients that would distinguish them from the electromagnetic pulse of a nuclear detonation.

To speed data reduction and analysis, a system known as "area gating" was tested. By this system the film records of electromagnetic transients originating within a 20-mile radius of the detonation were marked electronically, thereby reducing the amount of data that had to be analyzed. The "area gating" system was tried on six shots. On these events data were collected for about ½ hour, and the "area gating" system correctly marked the record for concurrent reduction and analysis. With the record so marked, operators were able to select the correct data, analyze it, and report the fix and detonation time in less than 15 minutes.

In the project involving the study of radiation effects on guided missile components, materials, and systems, the principal objective was to ascertain the effects of nuclear radiation on the guidance package of the NIKE-HERCULES guided missile. An exploratory investigation was also conducted to determine the effect of a nuclear environment on the propagation of X-band radar signals used to control a missile.

To fulfill the objectives of the radiation study, vacuum tube and transistor versions of the guidance package were exposed on shots Wilson, Owens, and Morgan at integrated neutron flux levels ranging from 11 orders of magnitude per square centimeter to 14 orders of magnitude per square centimeter. Dynamic responses of the circuits were monitored through time zero to about H±1 minute.

Post exposure studies on the packages are being conducted at Bell Laboratories to determine causes of circuit failure.

In the propagation study, attempts were made to measure the attenuation of X-band frequencies through the fireball and to ascertain the reflective characteristics of the fireball and nuclear cloud. To obtain the attenuation measurements a beacon transmitted energy through or near the fireball to a missile tracking radar, where the signal levels were recorded. The reflective characteristics were determined by transmitting energy toward the fireball and cloud with a target tracking radar and noting the level of the signal return.

Records of the attenuation measurements for various shots indicate the beacon signal was interrupted to some extent within the three-second period following time zero. On the Franklin shot, this amounted to a complete blackout for about 3 seconds. On the Kepler shot, where the beam of the beacon was sighted approximately one fireball diameter to one side of the device, the signal interruption was characterized by many missing pulses up to H±0.2 seconds, and by approximately 15 db of attenuation from H±0.2 seconds to H±1 second. Other data were collected but have not been analyzed as yet. There is some opinion that the signal interruptions were caused to a great extent by dust and other particles sucked up from the ground.

In the reflectivity investigation, signal returns from the fireball and cloud of several detonations were noted, but as in the attenuation measurements, it is not known whether these were caused by ionization or resulted from dust and other particles.

PROGRAM EIGHT

(THERMAL RADIATION MEASUREMENTS AND EFFECTS)

This program accomplished the following: investigated the thermal protection of the individual soldier, determined the effects of thermal radiation on a standard reference material, evaluated laboratory methods for determining the protection afforded by uniform systems, and tested some instrumentation systems.

For the protection of the individual soldier in the region of 5-25 cal/cm^2, 3 hot weather uniform ensembles, several shielding materials and a flashburn cream for the protection of the hands and face were tested. It was found that none of the uniforms would withstand the thermal input energies of interest to the Continental Army Command (CONARC) and remain usable. Two of the experimental uniform ensembles, nevertheless, offered some protection to the individual, while the one presently recommended for standardization did not. The primary difference in degree of protection between these is believed to be the result of the fire retardent treatment given the two new experimental uniforms. The one under consideration for standardization was not so treated, and flamed, producing severe and extensive burns, while the burns under the others were less severe and considerably less extensive. The shielding materials gave some protection to both the uniforms and the flesh where sufficient space between shield and the protected item existed, as would be expected. The flashburn cream appeared to provide fair protection to both levels tested, 15 and 25 cal/cm^2, and only a few small areas of burn were noted.

For the studies of thermal effects on a standard reference material, alpha cellulose papers were used as a reference standard to compare the results obtained in the field with those obtained in the laboratory. The data obtained indicated that laboratory methods for studying ignition of cellulose materials appear to be adequate as to radiant exposure, pulse shape, and geometry. Due to blast effects any definite differences in thermal effects due to aperture size could not be determined.

Two new types of passive colorimeters were tested, one developed at the University of Rochester and one developed at the Naval Material Laboratory. Both gave good results within the limits tested.

A streak spectograph system to be used for Operation Hardtack was tested by the US Naval Radiological Defense Laboratory, with satisfactory results.

Improved instrumentation of similar types to those used on Operation Redwing for making measurements inside the fireball were tested by the Wright Air Development Center. In addition, some new instrumentation consisting of various materials including ceramics, metals and plastics inserted in spheres and a ballistic shape, was tested to learn something of the effects of thermal and electrical conductivities and ionization potentials on the mechanism of ablation.

PROGRAM NINE

(SUPPORT PHOTOGRAPHY)

This program was primarily of a support nature and consisted of a single project which was concerned with:

1. Technical photographic support of the military effects programs.
2. The documentation of the overall military effects program and production of an effects motion picture.
3. The documentation of the detonations for release through Joint Office of Test Information, and for historical purposes.
4. The general photographic support of DOD projects.

For the purposes of technical photographic support, Program 9 provided camera instrumentation on 10 shots of the test series as follows:

SHOT	PROJECT	PURPOSE
Franklin	5.2	Blimp effects
	6.3	Cloud tracking
Lassen	2.10	Kytoon position and effects
Wilson	2.10	Kytoon position and effects
	6.3	Cloud tracking
Priscilla	6.3	Cloud tracking
	1.3	Shock wave photography
	3.6	Dome deflection
	4.1	Bio-medical photography
	8.1	Thermal effects
	8.2	Skin simulant effects
Hood	2.1	Cloud tracking
	8.2	Skin simulant effects
Pascal A	9.1	Gross effect views
Owens	6.3	Cloud tracking
	2.10	Kytoon positions
	1.2	Rocket launcher and canister positions
John	9.1	Fireball photography
	9.1	Cloud tracking
Smoky	6.3	Cloud tracking
	1.8	Shock wave photography
	1.8	Tank model photography
	5.2	Blimp effects

For the purpose of documentation of the weapons effects program, and the production of a military effects motion picture report, approximately 75,000 feet of color motion pictures were taken at the test site. This footage was planned and accomplished to cover the significant features of participation of each Department of Defense project. From this footage a military effects motion picture is being produced.

To document the detonation for historical purposes, and for releases to the press, both color and black and white coverage of each detonation was accomplished from an airborne camera station and a forward area manned camera station. This coverage consisted of still and motion picture photography. By the use of laboratory facilities established at the test site it was possible to process, classify and release coverage to the press within two hours after each detonation.

In general support of the participating DOD projects, approximately 5,000 still photographs were made at the Test Site. Immediate prints were produced for use of the projects. Laboratory facilities were also used to process microfile and oscillograph records as required.

Although some photography was lost due to unusually high pressures which destroyed the camera stations or unexpected radiation levels which fogged some film, the overall technical photographic effort can be considered successful.

F. CIVIL EFFECTS TEST GROUP PROGRAM

The Civil Effects Program broke into six major categories: (1) studies of fallout; (2) biomedical and physical aspects of prompt gamma and neutron radiation; (3) blast effects on structures; (4) biomedical effects of blast; (5) radiological contamination, decontamination, and training, and (6) instrumentation and supporting services.

Fallout studies were the most successful conducted in and around NTS to date. Fallout patterns were delineated and mapped in detail to distances of 600 miles from ground zero by aerial monitoring methods and ground survey teams. It was found that aerial surveys agree within 25% with gamma intensity measurements made three feet above ground. Several "hot spots" were delineated; one occurring at 78 miles had an infinite dose of 40 R (greater than 500 mr/hr at H±12 hours).

The detailed fallout maps materially assisted in refining the predicted megacurie yields of deposited activity presented by the Fallout Predictions Unit personnel during pre-detonation briefings.

For each shot studied, 200 to 300 fallout collecting trays were exposed and later processed in the laboratory to separate 14 particle fractions. From this material data were obtained on beta and gamma energy spectra and decay properties of debris by particle size and fallout time; radioactivity per particle relation as a function of size and time of fallout; certain physical and chemical characteristics relative to particle size and time of fallout.

Associated with the fallout studies, determinations were made of the persistence of fission products in tissues of native rodents and lagomorphs with special emphasis on the radioisotopes of , strontium, barium, cesium, cerium, ruthenium, zirconium, and plutonium. Determination was also made of the influence of detonation characteristics on the biological fate and persistence of radioactive debris at varying distances along the fallout pattern. Two detonations of approximately the same yield, one tower and one balloon shot were studied in this manner.

Important work was completed on measurement of the directional distribution of radiations at various distances from the hypocenter. For gamma rays, the physical quantity measured was the first collision tissue dose using chemical dosimeters developed by the School of Aviation Medicine. For fast neutrons both energy distribution and the first collision tissue dose were measured using threshold detectors developed at Oak Ridge National Laboratory.

It was found that the distribution for the case of gamma radiation was essentially peaked about the direction defined by the point of detonation and point of measurement. For fast neutrons the angular distribution can be represented by a spherical distribution plus a peak along the previously defined direction. In both cases the angular distribution is rather insensitive to the type of weapon and to distance from ground zero.

The data obtained will have great value as input for the determination of the amount of shielding afforded by any type of structure to prompt bomb radiations.

Measurements were made of gamma-ray and fast neutrons dose inside two identical Japanese-type houses at the same distances from ground zero for one shot. It was found that both

neutron and gamma-ray dose in the house varied by a factor of 2 depending on the exact location of a point within the house. The dose correlated rather well with the distance as measured from the point of entry into the house to the point of measurement along the ray path from the burst point.

It was also found that the dose measured at stations located on the side of a hill was essentially the same as for those stations located on level terrain at the same slant range from the point of detonation.

All of these data will assist materially in the determination of individual doses received by the Japanese at Hiroshima and Nagasaki.

Associated with the precise measurements of radiation dosages were the exposure of large and small animals to prompt bomb radiations. Mice, monkeys, swine, and burros were utilized to develop interspecies relationships and to correlate Plumbbob results with data obtained in earlier test series. Of particular interest was the response of burros to an acute dose. Of 88 burros exposed, 42 died within 3 days, a response pattern unexpected in severity and swiftness.

A major portion of the Civil Effect Test Group structures tests were in the form of FCDA-sponsored projects. These resulted in important measurements concerned with the design of reinforced concrete dome shelters, a dual-purpose garage shelter, a family shelter, and a modular reinforced brick unit. An array of 14 shelters designed by engineers in France and Germany and financed by those nations were tested at overexposures ranging from 75 psi to 200 psi. These foreign shelters were of more elaborate design than comparable U. S. structures, and they were exposed to pressures higher than those to which the U. S. civil shelters had been exposed previously. Accordingly, the results of this portion of the test program will be viewed with considerable interest by engineers.

Within the blast biology program, experiments were conducted to expand our understanding of the human side of protective construction with the objective of defining a biologically acceptable shelter environment. Data were obtained on the biological response to various patterns of overpressure; on the characteristics of blast-induced missiles; on the physical displacement of biological target by blast-induced winds; on results of the temperature

Figure 2-10. CETG Medical Studies.

rise inside a structure; and on the characteristics of dust in closed shelters. Associated work was accomplished on blast-induced pressures inside open structures in continuation of research on the design of shelters not requiring doors. A unique variation in effects phenomena was observed in connection with this program when it was found that dynamic pressure for Smoky exceeded by 40 to 60 times the dynamic pressure of Priscilla at approximately the same side-on pressure range.

A valuable radiological defense experiment was conducted by a Civil Effects Test Group which occupied a protective shelter in a region of heavy fallout. For the Diablo shot the overpressure at the shelter was approximately 4 psi, which did not approach its structural resistance proved in other tests to be above 25 psi.

From measurements made before and after fallout arrival, it was found that the shelter, having a minimum earth-cover thickness of 3 feet, provided an average shielding reduction factor of about 10,000. All openings in the earth cover for ventilation and other purposes were satisfactory from a radiological standpoint with the exception of the straight entrance way. The carefully designed shelter monitoring system provided adequate information. With one exception, all objectives of the second phase—the radiological recovery phase—of the experiment were met.

The Civil Effects Test Group supported practical training in radiological operations in the field. Under the sponsorship of FCDA, a group of exercises were conducted for radiological defense leaders selected from State and local civil defense organizations. Training included actual experience in ground and aerial monitoring in a fallout field.

A system of remote gamma radiation monitoring was carried out at stations at distances between 30 and 300 miles from the Test Site. The system reported off-site radiation intensities resulting from fallout by the mechanism of dialing the station through the commercial telephone network. Upon challenge, information was transmitted automatically by the station in the form of a coded signal. As a pilot study, the system was also utilized on-site for the guidance of personnel conducting post-detonation recovery operations commencing at H + 5 minutes. Instrumentation successfully reported on radiation intensity immediately after shot time at ranges where overpressures of 80 psi were received. This pilot effort conclusively demonstrated that early data on close-in radiation intensities may be obtained without the exposure of human monitors. The data obtained have also pointed the way toward developmental work to eliminate certain difficulties in detector performance and response.

Figure 2-11. CETG Program Shelter (French)

G. SANDIA CORPORATION PROGRAM

The conduct of projects having prime interest to and being sponsored by Sandia Corporation was embraced by Program 41 of Operation Plumbbob. The program included these separate projects:

PROJECT 41.1 - FIREBALL STUDIES

The objectives of this project were:

1. To continue exploration of the effects of close-in fireball phenomena on basic materials.
2. To continue exploration of the effects of close-in fireball phenomena on weapon components.
3. To gain further understanding of fireball physics.

The method of accomplishment was as follows:

A 24-inch diameter steel "Peace Pipe" was constructed in the center of the Fizeau tower. This steel column extended from a concrete shelter housing recording equipment at the base of the tower to within 175 feet of the weapon in the tower cab. The column was constructed of 20-foot sections of pipe joined together by large bolted couplings. The materials and components to be exposed were located in the couplings. The voids in the column were filled with grout to increase the inertia.

A portion of the components had their performance during the event recorded electronically in the shelter at the base of the tower. This was accomplished by running shielded cables through conduits from the couplings to the shelter. Magnetic tape recorders, oscillographs and oscilloscopes were used. Four 2-inch vacuum pipes extending from the shelter to four different elevations were used to measure gamma and neutrons versus time. The entire top 40 feet of the "Peace Pipe" was filled with helium and contained the primary fireball physics experimentation.

A large portion of the basic material study used 15 corrugated pipes buried flush in the ground and pointed at the device. These "pits" were 6 feet in diameter and 18 feet long, and were located at ground distances of 500 to 2,800 feet. The material samples were mounted at the ends of the pits. This arrangement minimized the effects of missile damage on the samples. Additional material samples were mounted on two large steel billets located beneath the tower cab on the side of the tower. The billets acted as inertia carriers to facilitate recovery.

The "Peace Pipe" was photographed by high speed cameras located on Red Rock Butte and the hill east of the control point. Preliminary results can be found in ITR Report Nos. 1516, 1517, 1518, and 1519. Final results will be published as WT Reports of the same numbers.

PROJECT 41.2—

WEAPONS VULNERABILITY

The objectives here was to increase the general knowledge of the vulnerability of nuclear weapons to nuclear bursts and, in particular, to demonstrate the capability of Sandia Corporation to build a tough nuclear device as similar as possible to an actual weapon. This project was tied intimately to Project 41.1. The two provided a vulnerability study ranging from basic materials through weapon components to completed weapons.

Eight tough modified [ ] were located atop 250-foot and 275-foot television towers within 250 to 400 feet of Fizeau bomb zero. The units were complete weapons with the exception of high explosive and nuclear material. Six nominal units contained magnetic tape recorders which monitored pressures, accelerations, and fuzing and firing functions. One extra tough unit and one weaker unit were not instrumented but depended entirely on "before and after" inspection.

These tough [ ] were also photographed by high speed cameras located on Red Rock Butte and the hill east of the control point. Preliminary results can be found in ITR Report No. 1520. The final results will be published as a WT Report of the same number.

PROJECT 41.3—

NEUTRONS VERSUS ALTITUDE

The goal of this project was to determine the effect of ground terrain on the measurement of free field neutron flux.

Foil detectors were located on the ground and on the vertical mooring cables of 23-foot diameter polyethylene balloons. The activations of the ground and altitude foils were compared. The balloons were photographed from two camera stations at zero time to determine their space position.

The balloon array used on shot Wilson was as follows:

1. A balloon string 900 feet from ground zero to an altitude of 700 feet.

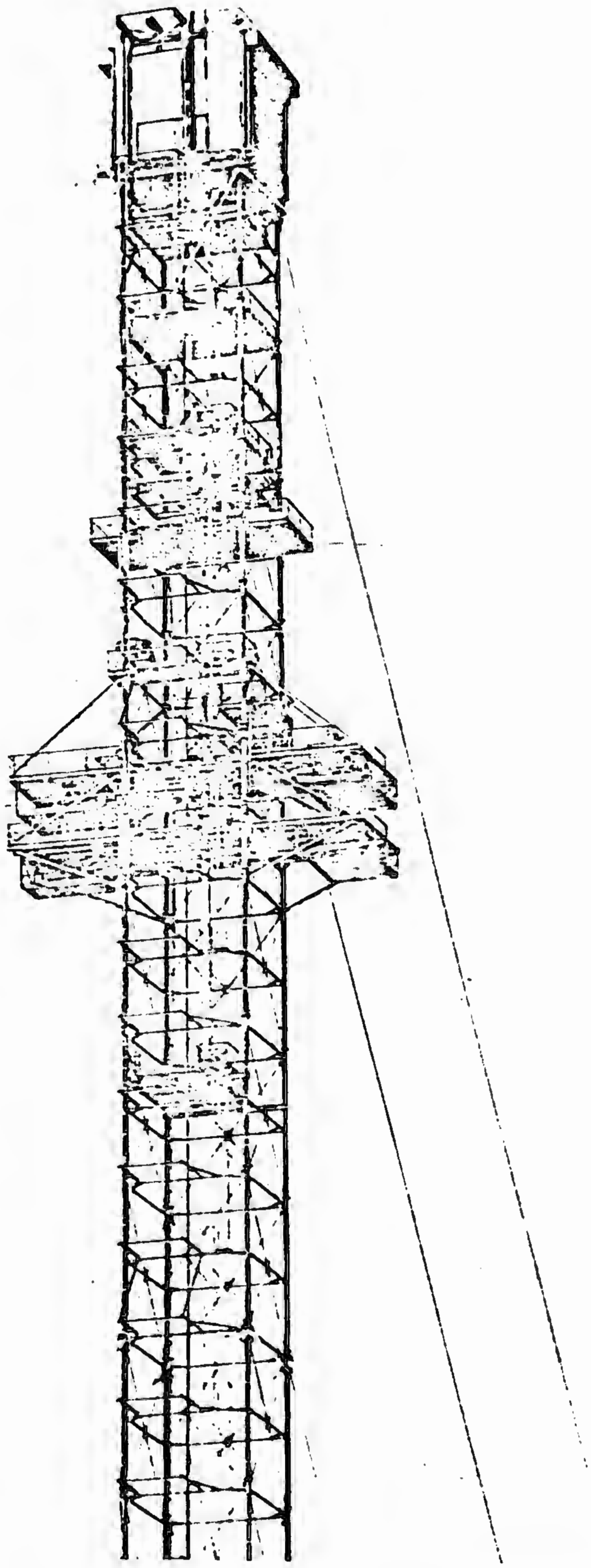


Figure 2-12. Typical Tower Cab and Instrumentation Platforms.

2. A balloon string 1,800 feet from ground zero to an altitude of 1,200 feet.

3. A balloon string 2,700 feet from ground zero to an altitude of 1,500 feet.

4. A balloon string 3,600 feet from ground zero to an altitude of 1,500 feet.

Preliminary results can be found in ITR Report No. 1521. The final results will be published as WT Report of the same number.

H. TG 57 PROGRAM

INTRODUCTION

The first concern, as with any nuclear weapon is one of safety from nuclear yield in case of accidental explosion by static spark ignition, impact ignition, fire, etc. First testing of a weapon of this type must focus upon assuring nuclear safety. Projects 56 and 56B, performed by Los Alamos and the University of California Radiation Laboratories, respectively, were devoted to this end. Termed one-point safety tests, they checked the devices in question by firing the weapons at one detonator location.

Obviously no weapon can enter production scheduling and ultimate stockpiling until a pronouncement of one-point safety can be defended.

With nuclear safety from one-point firings assured, an insidious though less significant problem remains: plutonium contamination. Plutonium is an alpha emitter and therefore no real external hazard; fortunately, the oxides of plutonium formed in a one-point detonation are essentially insoluble in the fluids of the GI tract (0.003%). Once in the stomach their stay in the body is short since they are excreted practically as an inert material with virtually no body assimilation. Inhalation is a different mechanism entirely and one which does hold considerable threat. Any particle small enough to reach the lower respiratory tract apparently has an excellent chance of clinging to alveolar surfaces and staying to do radiation damage locally with a half life of approximately one year. Some of the finer particulate matter captured may be taken into the blood stream over a period of several days. This material stays as a blood burden until its trace solubility allows eventual assimilation to the extent of some 70 percent of the material carried. (Actually 70 years is judged sufficient to allow only 34 percent of body equilibrium to obtain). This 70 percent is distributed principally to the bone where it resides indefinitely as far as human life span is concerned. One cannot outlive the influence since the alpha half-life of plutonium is on the order of 20,000 years.

With the introduction of plutonium-bearing weapons we then have a series of new problems. A rough list of the stages at which accidents might occur is as follows:

1. First mating of high explosive and plutonium, assembly structures, etc.
2. Loading finished weapons for shipment to storage sites and other receival areas.
3. Actual transportation to storage or receival sites.
4. Charge-out from storage by military for training, defense flights, scrambles, etc. (Handling, jettison and crashes).
5. Movements of weapons within a storage site for inspection or surveillance.

One such weapon is now available, is issuing from production lines, and is being transported and stored. Specifically, the MB-1 air-to-air rocket, is entering stockpile in significant numbers. Present regulations concerning handling and shipment are based upon fragmentary data collected from a secondary experiment in the nuclear safety tests by Los Alamos and Sandia Corporation in Project 56 performed in November, 1955, and January, 1956.

Late in December, 1956, the AEC Albuquerque Operations Office, with the sanction of the Department of Military Application (DMA) asked Sandia Corporation to assume responsibility for arranging an extensive experimental program to evaluate plutonium contamination from one-point detonation Sandia accepted the task and appointed a director for the test.

The Test Director called together representives of DMA/AEC, Hq/AFSWP, ALO/AEC, AFSWC/USAF, FC/AFSWP, LASL, AEP/Rochester, UCRL, AEP/UCLA, DBM/AEC, SC, LVB/USWB, LVB/USPHS and REECO on January 18, to rule on a choice of test site and to formulate first experimental plans. These beginnings evolved into the experimental programs outlined here.

EXPERIMENTAL PROGRAMS

The large valley adjacent to and northwest of Groom Lake was borrowed from the USAF for a 200-day period and designated Area 13 as a temporary addition to NTS. Seventy square

miles of the valley area (more than 100 square miles) was surveyed for instrument and fallout collector locations. Earth samples analyzed radiochemically confirmed the belief of insignificant plutonium background from previous NTS operations.

1. PROGRAM 71–– PARTICULATE PHYSICS

Objectives were:

a. Measure plutonium distribution at the surface and concentrations in the air as a function of time after detonation.

b. Construct a fallout model which can be used for any wind pattern.

c. Check fallout characteristics of plutonium against those of uranium (Fractionation).

d. Learn something of the physical nature of the fallout particulate (size, shape, density).

The experimental approach was to comprise a fallout collector array consisting of some 2000 to 4000 sticky pans distributed over a very large area (10 to 50 square miles); an array of air samplers on the ground; high-speed photography on the burst to help study the jetting action and the motion of various portions of the cloud in the expected high shear wind structure; soil samples collected immediately after detonation and for a period of six months thereafter at calculated intervals; a series of balloon-borne precipitators flown 500 feet from burst point to collect particles from the early clouds at about six height levels; and wind temperature measurements prior to, at, and after shot time to determine the precise wind structure existing for the period of detonation and the subsequent one during which fallout occurs.

2. PROGRAM 72— BIOMEDICAL FIELD STUDY OF PLUTONIUM INHALATION

Objectives:

a. To study the environmental short term and chronic fates, and persistence of plutonium debris resulting from a subcritical detonation.

b. To study the rate of environmental decay of plutonium debris in selected areas of contamination.

In broad terms, the experimental program consisted of the following: a group of dogs for exposure to cloud passage, plus a much larger group of 70 to 80 animals placed post-shot for chronic exposure; a serial sacrifice schedule destining all animals except spares for autopsy ar ssection of the following tissues: trachea, nasal mucosa, complete lung, lymph nodes, liver, long bones, spleen, plus kidney and GI tract in some cases; and, for a limited number of dogs, metabolism cages to provide urine and fecal analyses from which body burden and rate of clearance could be judged. The original plans also allowed for the use of additional animal species in the experiment, principally rats, burros and possibly sheep.

3. PROGRAM 73— PLUTONIUM MONITORING AND DECONTAMINATION

The broad objective of this program was to study and develop methods and techniques suitable for decontaminating large surface areas contaminated with plutonium as a result of a one-point detonation.

The experimental approach consisted of investigation of decontamination techniques suitable to removal of plutonium from (1) large land surface areas in the test areas (soil); (2) concrete and asphalt pads of reasonable size; (3) materials used in equipment and building construction, such as concrete, wood, stucco, brick, aluminum and steel, in both horizontal and vertical attitudes. In mind were several decontamination techniques: washing, vacuuming and steam cleaning, plowing, leaching with water, and fixation and subsequent removal of land surface layers.

4. PROGRAM 74— SURFACE ALPHA MONITORING

In evaluating the scope of the experimental plan presented in the Particulate Physics committee report, it was decided that a large-scale monitoring survey to be performed as a correlate of the sticky-pan experiment was too large an undertaking to be considered as one of many projects under a single program director. For this reason, about February 10, a separate program (74) was created to have sole responsibility for performing a field survey of plutonium contamination with alpha-monitoring instruments. Consideration of Program 74 by the group assigned the study led to the decision that broom-finished concrete slabs would be placed throughout the field adjacent to sticky-pan collectors for use as a uniform monitoring surface and the principal survey reference. Measurements directly on the soil and brush were to be made, but not to the extent indicated for the standard surface.

OPERATIONS

A target shot date of April 3, 1957, was chosen at the general meeting of Test Group 57 personnel on January 18, 1957. However, a week or two previous to this it became clear that operational readiness could not be attained until April 10; a new first shot date was declared

accordingly. The hours 2100 to 2400 were preferred for the shot but the 8 to 10 hour preparation time for the balloon-borne air sampler array and the gusty afternoons typical of daily "heat lows" in Nevada forced the second choice of 0400 to 0700 hours. Even so, weather prevented shooting for 14 days.

1. THE SHOTS

At 0350 PST, April 24, a surface charge of 110 pounds of stick dynamite was fired 1000 feet east of the instrumented area to verify prediction of cloud height for the burst during the morning temperature inversion. The cloud apex was triangulated from two manned transit stations to get the height measurements.

The was actually fired at 0627 PST, April 24, in Area 13. The winds at shot time and during the ensuing period of 1 to 2 hours were measured from balloons released about 1300 feet east of ground zero and viewed by two theodolite stations more than 12,000 feet away. The winds were so light that the resolution of this observation system appears to have been inadequate. As a consequence the fallout pattern, sequence cloud-photographs from the south and west and aerial movies probably will give, when combined, a truer measure of shot time winds.

2. THE WEAPON

Sandia Organization 5212-2 handled, placed, and armed the weapon, in cooperation with the EG&G Timing and Firing crew. The instant of firing was not critical, since time-correlated instrumentation was practically nonexistent. Timing and firing circuits were the ultimate in simplicity and the weapon was hand fired by EG&G.

CONCLUSIONS

1. PLUTONIUM ON THE GROUND

Isoconcentration contours have been inferred both from sticky-pan analyses and alpha survey instruments. The sticky-pan contours are good enough for planning against accident situations. The discrepancy that exists between soil-sample assays done by Columbia University for Program 73 and the sticky-pan analyses for Program 71 must be resolved, either by relating the chemical procedures employed by the separate analytical groups or by explaining differences in terms of the two methods of sampling.

It must be emphasized that wind structure is the important factor. The contours reported here obviously manifest fallout from a burst on the ground and in the open, at the bottommost detonator in a specific wind structure and in a specific type of soil. Success, information-wise, can be claimed for the basic experiment only when data interpretation can lead to the inference of a fallout model that will permit computation of plutonium distribution for any chosen or experienced wind situation.

2. PLUTONIUM IN THE AIR

While much information on air concentration, undefined by previous experiments such as Project 56, have resulted from TG 57 investigation, the actual maximum air concentration existing for the shot conditions of the TG 57 test was not determined. Guesses from the fragmentary data of Project 56 led TG 57 planners to believe that the 5000-foot array of air samplers would be situated well beyond maximum air concentration levels. This may or may not have been the case. All that can be said is that the maximum air concentration measured was at a 5000-foot station. It is important, however, that at this distance of 5000 feet the width of the area over which higher concentrations could be expected was rapidly disappearing, and only a narrow spike-like area could have received significant air concentration beyond 5000 feet. While samplers were in the field beyond this distance, their spacing was such as to miss this hot line.

3. PLUTONIUM IN THE DOGS

A sweeping consideration of dog tissue burdens of plutonium leads one to conclude that acute exposure is more hazardous than long-term exposure in a dusty desert area (i. e., Nevada). This conclusion, however, stands short of real defense in that air samples taken during the entire chronic exposure have not been measured as yet, nor have wind velocities versus time been reduced to interpretable form. The chronic-dog stations were chosen to lie along a southwest wind line; i. e., they were situated at a bearing of some 30 degrees with respect to ground zero, since it was believed that climatically the most probable winds were southwesterly. If, for the specific period of exposure, this assumption were incorrect, there may well have been other positions in the field for which larger inhaled quantities of plutonium could have resulted.

Finally, the process of clean-up or biological or physiological recovery from chronic inhalation, will become part of the study. The lung model now used for computing inhalation hazards can be evaluated to some extent by the rather extensive dog data that will accrue.

4. PLUTONIUM REMOVAL AND FIXATION

Natural influences caused rather rapid "apparent" decreases in contamination levels.

Repeated surface monitoring indicated that smooth surfaces decreased by a factor of 10 by D+7 and 5 by D+24. Soil decreased by a factor of 15 by D+7 and 40 by D+24.

Air-sampling stations 500 feet north of ground zero indicated on the average a concentration of the order of 35,000 dpm/m³ for the three hours immediately post-shot. Succeeding air samples show airborne contaminants down by as much as a factor of 100 by H+7.

General efficiencies in percent for pad decontamination are as follows: sand blasting - 98.8; water-detergent scrubbing --98.6; water-detergent hosing -98.6; water hosing -96.1; water scrubbing 94.6; steam cleaning -28; and vacuuming -66.

General efficiencies in percent for large-area earth decontamination or fixation are as follows: plowing -98.3; oiling and scraping -98.2; scraping- 95.6; leaching with 0.3 inch of water, and scraping -93.2; oiling (CRG-0 road oil) -89; leaching with 1 inch of water -85; leaching with 0.3 inch of water-$FeCl_3$ solution —33; and leaching with 0.3 inch of water-Alconox solution -3.

5. OTHER DATA

Many data are now in hand. Still more will become available in the next several months. Some classes of data are completely absent. No diffusion-tray results have been reported. No Program 71, and few Program 73, soil samples are available. The balloon precipitron data from which inferences can be made concerning constitution of the cloud, distribution of plutonium and uranium therin, etc., are unavailable. Air-sampler and wind data for chronic-dog lung-burden interpretation are missing. The spare dogs, six from each of the chronic dog stations, plus four acute-test chronic dogs, have been started on a two-year observation period during which serial sacrifices, including tissue-assay work, hematology, pathology, and metabolism checks will be done. Resuspension experiments at 12 and 24 weeks post-shot remain to be reported, as well as alpha surveys of the area at these times. Numerous slides had been set out by USNRDL for electron microscopy and autoradiography; their analysis may give valuable information.

Attempts have been made to cite gross conclusions indicated by data on hand. Consideration of all data by each of the programs separately, interrelating the work of the programs into a complete entity, plus the development of a fallout model, should provide an excellent assessment of plutonium contamination from an accidental detonation of a

I. NEW TEST TECHNIQUES — BALLOONS

Sandia Corporation was assigned the responsibility of suspending nuclear test devices from balloons during Operation Plumbbob. The pay loads suspended ranged from 1800 to 4400 pounds and the shot altitudes ranged from 500 to 1500 feet above grade. Project 64.1 was responsibile for the balloon suspension system and Project 64.4 was responsible for the device support structures.

Balloon installations were constructed in Areas 7, 9, and F. An area installation consisted of three guy winches, each 3000 feet from ground zero and displaced at 120 degrees. These winches were housed in concrete shelters covered with earth to prevent blast damage. A main winch was housed with a guy winch in one shelter. The main cable ran along the ground to ground zero, through a sheave, and then vertically to the balloon cab. The guy cables ran directly from the winch shelters to the balloon cab. The balloon's altitude was controlled by the main cable and the balloon's horizontal position was controlled by the guy cables. All winches were capable of being operated remotely from the control point as well as from ground zero.

The balloons used were manufactured by General Mills, Inc. at Minneapolis, Minnesota. They consisted of a 2½ mil polyethylene liner inside a SN-171 nylon shroud and were roughly pear shaped when inflated. A nominal 67-foot diameter balloon was used for the lighter loads and lower altitudes, and a nominal 75-foot diameter balloon was used for heavier pay loads at 1500 feet. The small balloons used 7/16 inch main cables and 5/16 inch guys. The larger balloons used ½ inch mains and ⅜ inch guys.

A deflation system was mounted on top of the balloon. It consisted of nichrome wires which when shorted across a Ni-Cad battery became hot. One wire cut through the nylon and polyethylene where it was gathered at the top of the balloon. A hole approximately 4 feet in diameter was opened for the gas to escape. If the first wire broke, the second wire was automatically actuated. The deflation system could be initiated remotely from the control point by depressing two push buttons simultaneously or would actuate automatically by baro switch 2300 feet above grade.

Two television cameras were mounted at ground zero looking vertically upward. Their output was transmitted via microwave to the control point by a microwave transmitter located in the main winch shelter. A complete dual

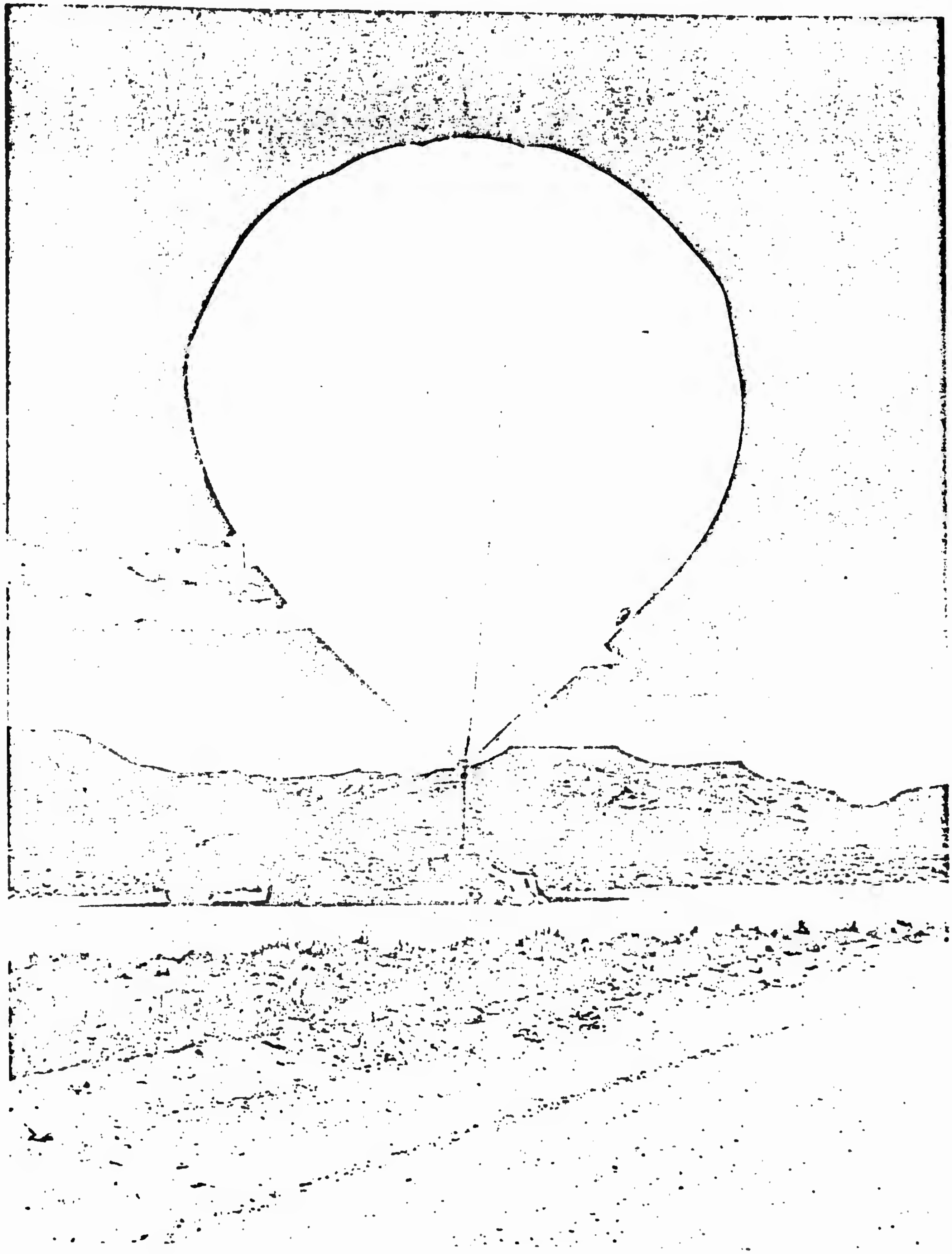


Figure 2-13. Inflated Balloon.

system was used to provide reliability. Observation of lights on the bottom of the balloon cab by means of the cameras permitted remotely controlled horizontal positioning.

All remote controls were combined into one operational console located in the control room at the control point. Here a console operator could run the winches, observe cable footages, observe cable tensions and monitor the balloon's position by television. This one console was used in conjunction with all balloon areas by switching plugs.

Electrical signals were fed to the device cab through a 19-pair electrical cable hanging from the balloon cab. This cable was flaked out in a cleared area prior to going to altitude and was restrained merely by ground drag. It was terminated in a stub-out which in turn was connected to a timing bunker.

Details of the balloon suspension system can be found in SC Report 3893 (TR) dated September, 1956, entitled "The Operation of Balloons for the Suspension of Nuclear Test Devices."

PRE-OPERATION TRIALS

Sandia Corporation began flying balloons at Nevada Test Site in January, 1957, to determine the balloon's drag coefficient, the reliability of the system, the positional accuracy in varying winds, and most important, to gain as much experience as possible before the operation started. The following summarizes the results of these trials:

1. The drag coefficient of the balloon was on the order of 0.4 in winds of 20 miles per hour or less. The drag coefficient increased as the wind velocity increased because the balloon deforms.

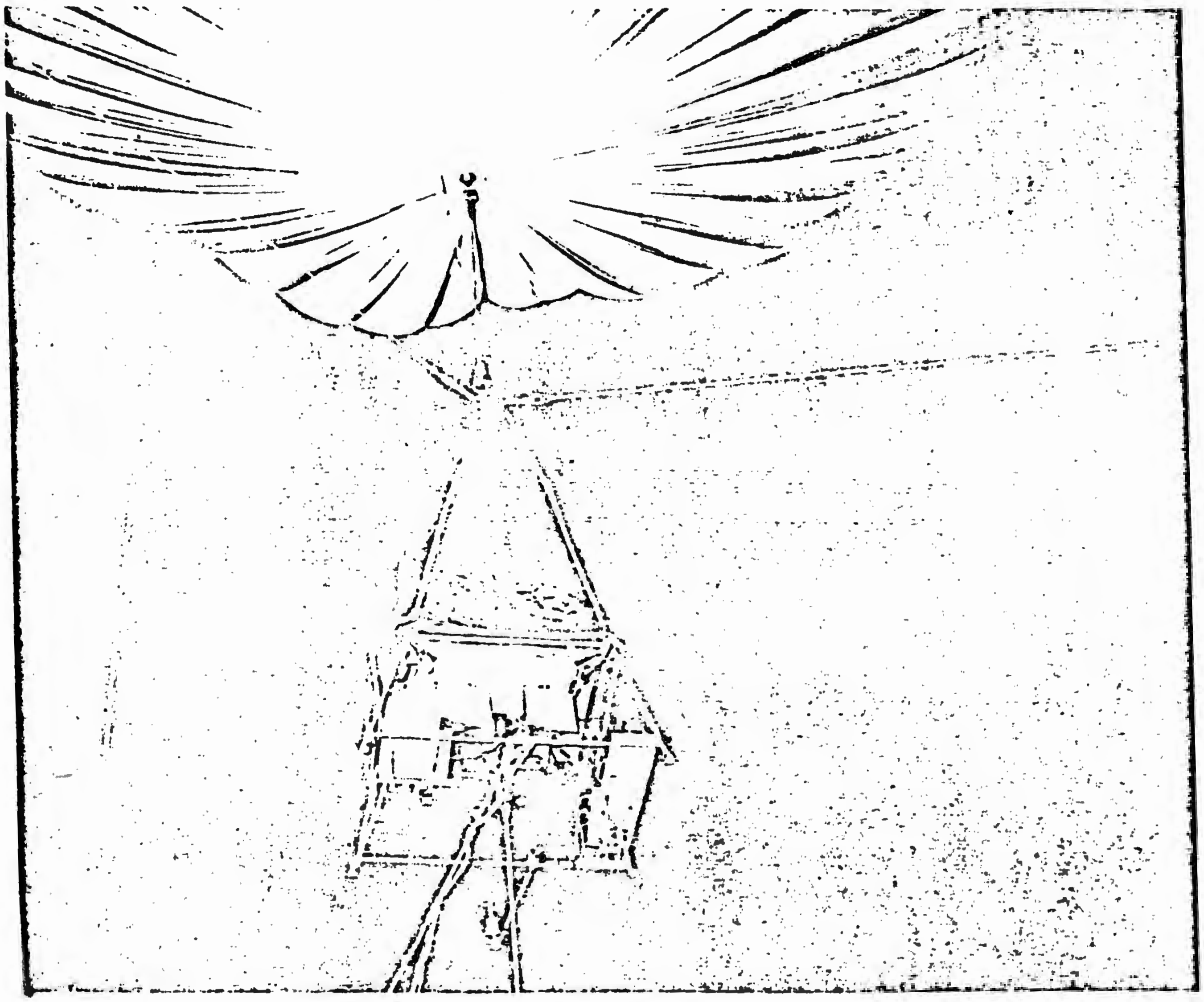


Figure 2-14. Balloon with Device in Place.

2. The balloon positioning with nominal pay loads was generally good (+30 feet at 1500-foot elevation) in winds less than 20 miles per hour.

3. Balloons flew repeatedly in winds of 35 to 45 miles per hour; however, gusts in this range resulted in the loss of some balloons due to tearing of the polyethylene liner and the consequent slow loss of helium. The experience gained indicated that personnel safety and handling ease decreased rapidly as the wind velocity rose above 20 miles per hour, dictating 20 miles per hour as the operational wind limit.

4. A 67-foot diameter balloon with a 2000 pound cab attached was released free from the surface of the ground. The balloon reached an altitude of 5000 feet above the surface before it self-ruptured. The cab with the deflated balloon attached struck the ground at a velocity of 120 miles per hour 5800 feet from the point of release in 2 minutes and 41 seconds.

5. A 67-foot diameter balloon with a 2000 pound cab attached was released from the surface of the ground with 1500 feet of slack ½-inch diameter main cable attached to the cab. The cable pulled taut with no apparent damage to any part of the system and without exceeding the elastic limit of the cable.

6. The deflation system was manually actuated and an average rate of lift-loss was measured at 33 pounds per second.

7. A high rate of inflation failures necessitated redesigning the liner.

OPERATIONAL PROCEDURE AT NEVADA

Coordination for the LASL cabs was done by a Project 64.4 representative at Albuquerque to provide close correlation of cab requirements.

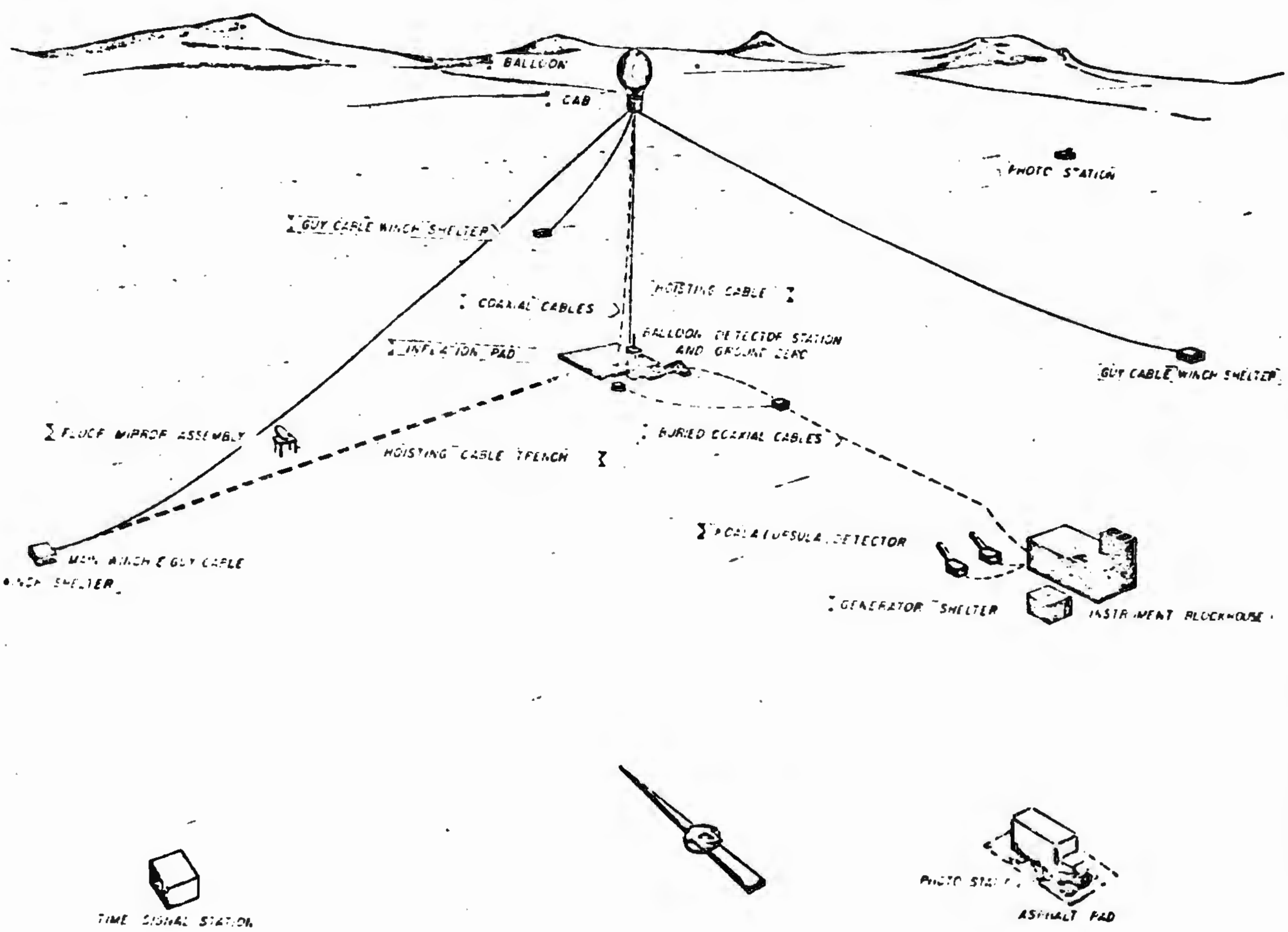


Figure 2-15. Area 9 Schematic.

UCRL cab assemblies were coordinated by Sandia representatives at the Livermore branch. In order to assure correct assembly of all components on the cabs, mock-up assemblies of the systems were made at the individual laboratories before the device cabs were shipped to Nevada Test Site. Each cab was also tested to 20,000 pound tension. Assembly of all components except device was made in the Staging Building in the Sandia Compound at Nevada Test Site and the complete cab was moved to the appropriate balloon area on a special trailer designed for transporting the device cab.

A 16-foot by 16-foot plywood shelter was used to house the device cab in the vicinity of ground zero. This house was usually ready for occupancy four days before the event. The device cab was moved to the Zero Area at this time. Dry runs were begun to insure proper operation. During this same time new steel balloon cables were put on the winches and tested, and a balloon system electrical checkout was completed. Originally, altitude dry runs were taken with the device cab; however, these were eliminated by mid-operation as confidence in balloon system was gained. The balloon was usually inflated on shot night on a large concrete pad located at the "Y" Junction. It was then hauled on a low-boy outfitted with a 16,000 pound concrete block to the appropriate balloon area. A balloon cab weighted with lead and having spotting lights attached was put to altitude and positioned in conjunction with the diagnostic personnel. Television screens were marked to indicate the proper zero position to be repeated. The main cable footage and tension were also recorded so the altitude positioning could be repeated.

At the conclusion of the alignment with the weight cab, the cab was returned to the ground and transferred off the balloon. Approximately 3 hours before zero time the device cab was transferred to the balloon and the arming commenced. One member of the balloon crew stayed at zero as a member of the Arming Party. When arming was completed, all personnel returned to the control point and the balloon was remotely started to altitude.

The following table gives data pertinent to each balloon event. A detailed operational report will be published as WT Report No. 1522.

Shot	Date	Area	Nominal Altitude	Payload	Balloon Size	Shrouds Expended	Liners Expended	Winds at Altitude	Position in Error	Days Delay Due to Balloon Winds	Days Delay Due to Balloon System Readiness	Helium Expended
Lassen	6/5	9	500 ft.	2070#	67' diam.	3	3	5-8 mph	1'	0	0	399,000 cu. ft.
Wilson	6/17	9	500 ft.	2380#	67' diam.	2	2	18-20 mph	4½'	3	0	266,000 cu. ft.
Priscilla	6/24	F	700 ft.	2516#	67' diam.	1	1	2-4 mph	1'	0	0	133,000 cu. ft.
Hood	7/5	9	1500 ft.	2906#	75' diam.	1	1	5-7 mph	2'	1	1	196,000 cu. ft.
Owens	7/25	9	500 ft.	2120#	67' diam.	2	3	11-14 mph	2'	0	0	399,000 cu. ft.
Stokes	8/7	7	1500 ft.	2655#	67' diam.	3	3	7-9 mph	2'	2	0	399,000 cu. ft.
Doppler	8/23	7	1500 ft.	2455#	75' diam.	2	3	2-4 mph	1'	2	2	588,000 cu. ft.
Franklin Prime	8/30	7	750 ft.	2719#	67' diam.	1	1	1-3 mph	1'	0	0	133,000 cu. ft.
Wheeler	9/6	9	500 ft.	1896#	67' diam.	1	1	13-14 mph	1'	0	0	133,000 cu. ft.
Laplace	9/8	7	750 ft.	1916#	67' diam.	1	1	5-12 mph	1'	0	0	133,000 cu. ft.
Newton	9/16	7	1500 ft.	4355#	75' diam.	1	1	8-12 mph	3'	0	0	196,000 cu. ft.
Charleston	9/28	9	1500 ft.	3700#	75' diam.	1	1	3-6 mph	1'	1	0	196,000 cu. ft.
Morgan	10/7	9	500 ft.	1980#	67' diam.	1	1	20-25 mph	5'	1	0	133,000 cu. ft.

J. NEW TEST TECHNIQUES — TESTING IN TUNNELS

INTRODUCTION

Early in 1956, Griggs and Teller proposed the testing of nuclear devices by means of contained underground explosions. The primary advantage of such a method lies in the virtual elimination of fallout and its controversial effects. The cost of maintaining the off-site blast and radiation monitoring net, weather and fallout prediction services, military support and delays due to weather could also be eliminated. Other nuisances such as off-site blast effects, tracking of the radioactive cloud and its effect on airline operations, and the concern about eye injury from the bright flash would be eliminated.

Figure 2-16. Rugged Terrain of Area 12.

These advantages of underground testing are significant only if it is possible to obtain the required diagnostic information. It appeared at the outset that certain types of information relying on

, would be better adapted to an underground environment than to towers. The primary problem centered on the question of yield measurements.

Historically, all diagnostic tests have been air bursts. Tests in other media have taken place primarily to study the effects on the medium rather than the properties of the device. The time honored yield determinations come from radiochemistry and early shock growth measurements in air (fireball photography). In an underground location, these measurements cannot be performed in their usual sense. Therefore, if underground testing was to compete with other methods, these measurements had to be adapted to an underground environment or new and equally accurate measurements had to be developed.

In addition to the primary question of the yield measurements were other problems such as depth of overburden for containment, costs, damage to structures due to ground shock, and ground water contamination, that had to be resolved.

In the spring of 1956, the Test Division, UCRL-Livermore, undertook to study the feasibility of underground testing in the light of the foregoing considerations. These problems were studied in detail by B. Sussholz and later G. T. Pelsor. Since there was no previous experience with deep underground nuclear explosions, it was soon apparent that theoretical studies and extrapolations from previous HE and nuclear shots could give only partial answers. It was with the intent of obtaining more conclusive answers to these questions that a deep underground test (Rainier) was included in the UCRL program for Operation Plumbbob. Plans were laid to drive a tunnel into the side of a mesa located in the northwest corner of the Nevada Test Site (Area 12) and to detonate a low yield device at the extreme end where the overburden would be sufficient to contain the explosion.

The approach here was to use a device of known yield whereby the questions of yield and effects could be more readily evaluated. The (1.7 kiloton yield) was selected as the device for the Rainier event. This choice was based on the following consideration:

1. The limitations of time and money dictated the choice of a device that was reasonably available and of such yield that it could be buried at a safe depth with a minimum of digging.
2. The yield and alpha versus time had been measured.
3. The dimensions of the device were such that it could be easily maneuvered in the limited space of a tunnel.

PHYSICAL ENVIRONMENT

1. SITE LOCATION

A section of the mesa slope along the tunnel direction is shown in the figure below. The hill is capped with a layer of welded tuff (rhyolite) of approximately 200 feet thickness. Beneath this lies a fairly homogeneous formation of tuff (Oak Springs formation) extending about 2,000 feet to a basement rock of limestone. The tuff of this formation is a light porous material having favorable properties from the standpoint of mining and energy absorption.

2. DEPTH OF OVERBURDEN

The overburden necessary for containment was studied in detail by Sussholz and Pelsor. By "containment" it was meant that an appreciable fraction of fission products (say 90 percent of more) would not reach the surface. There is an abundance of data relating the effects of HE shots buried in various soils over a range of scaled depths. The application of these data to nuclear explosions must be done with caution due to the extreme disparity in the two types of explosives. Previous underground nuclear shots were buried at such shallow scaled depths that the associated data could only be indicative. After considerable study of this question, it was concluded that the depth of overburden for containment could be expressed by d_c (feet) $= 300\ W^{1/3}$ kilotons. Due to the pioneering nature of the proposed test a safety factor of two was introduced into the overburden. For a yield of 1.7 kilotons, $2\ d_c = 700$ feet. The location of the device in the actual tunnel provided 900 feet of cover vertically and 800 feet to the nearest point on the mesa slope. The net horizontal distance of the device location from the portal was 1672 feet. The total length of tunnel dug was 1942 feet.

3. TUNNEL DESIGN

The basic design criteria for the tunnel were:

a. Access to the device at all times (necessary in case of a misfire).

b. The tunnel should close off near the point of detonation to contain the radioactive debris.

Pelsor suggested a design that appeared to meet these requirements (see figure). The design simply involves the termination of the tunnel in a spiral-like configuration such that the shock running out in the rock closes off the tunnel before the air shock in the tunnel reaches that point. The shot room itself was plugged with 13 feet of sand bags. This was a compromise between criteria (a) above and the necessity of containing the explosion long enough so that it appeared to be in an isotropic medium

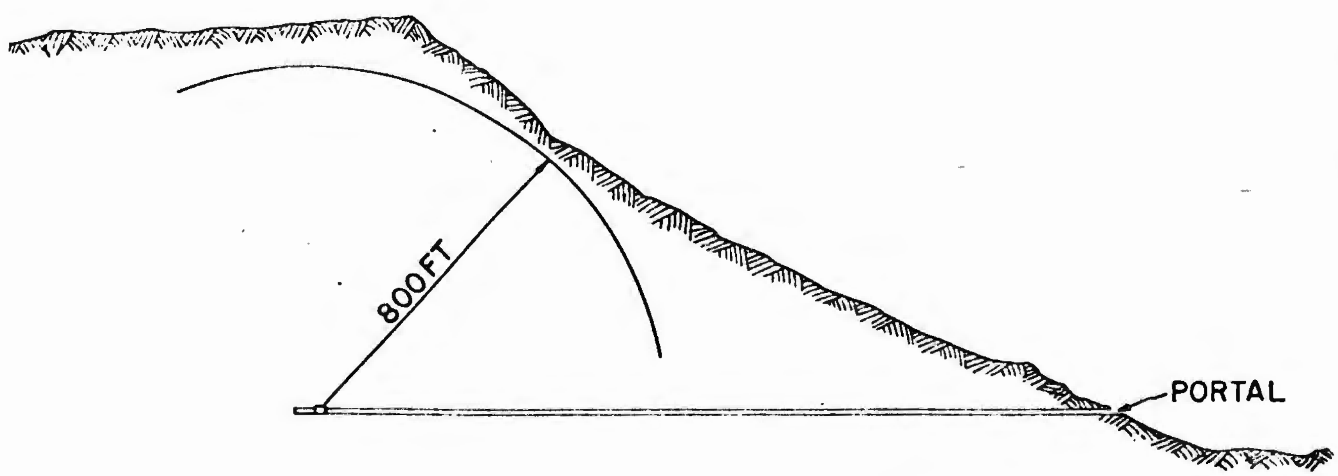


Figure 2-17. Section of Tunnel Mesa.

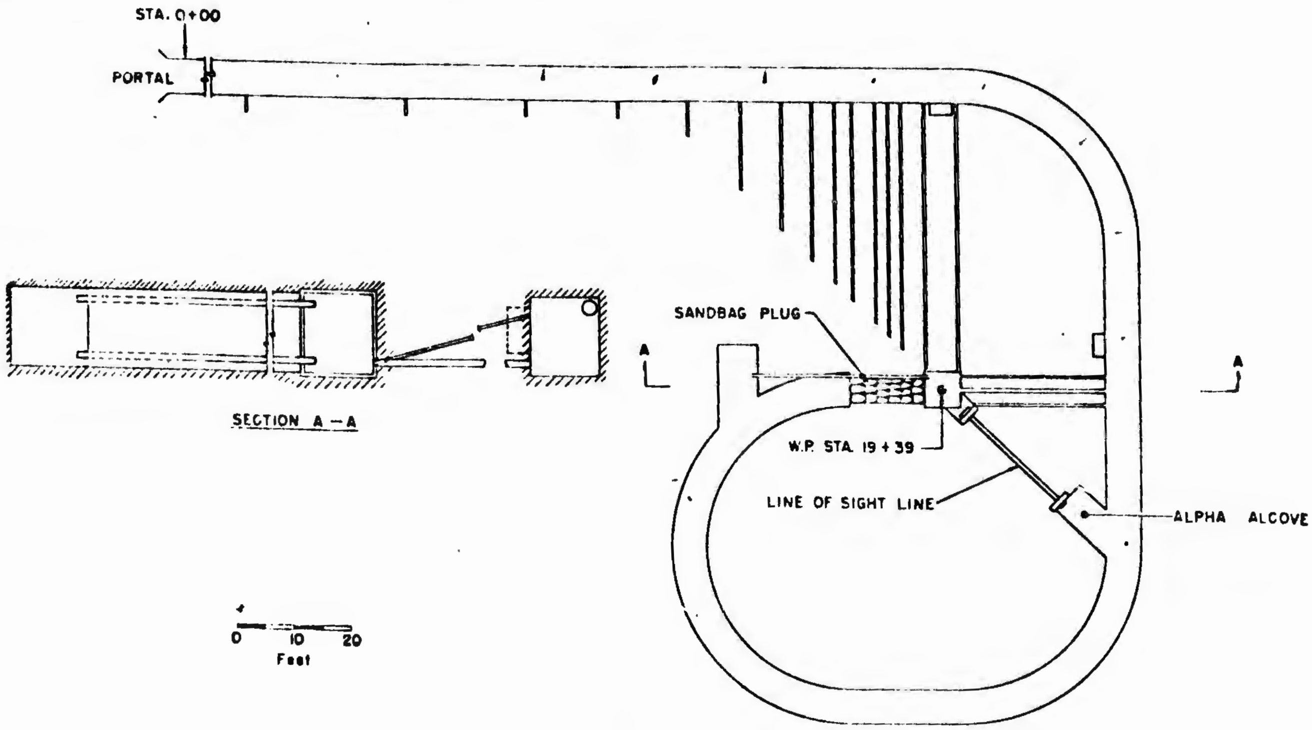


Figure 2-18. Plan of Tunnel.

to the close-in measurements. This plug also delayed the air shock long enough to save several hundred feet of additional tunnel which otherwise would have been necessary in the Pelsor closure mechanism. Two blast doors designed to withstand at least 5 bars overpressure were installed at Stations 3+50 and 11+00. Between these doors the tunnel was offset 20 feet from the original centerline. These precautions were taken to minimize a shotgun effect in case the tunnel did not self-seal.

SCIENTIFIC PROGRAM

1. DIAGNOSTICS

As stated previously, the primary diagnostic problem centers around yield measurements. During the initial feasibility study of underground testing, a number of yield determinative techniques were studied by G. T. Pelsor and W. H. Grasberger. These studies indicated that shock growth measurements and radiochemistry as adapted to an underground environment offered the best chance for good yield measurements. The concept of the diagnostic program, therefore, was to measure the alpha of the device as a check on its performance and to develop new yield techniques to check against the known yield.

The Rainier diagnostic program is described below:

PROGRAM 21 — RADIOCHEMISTRY

Project 21.1—Radiochemical Yield

Griggs & Teller suggested that the yield of an underground burst might be determined by performing radiochemical analysis of core samples obtained by drilling into the residual cavity. The radiochemistry per se is expected to proceed along conventional lines. Obtaining core samples from a region of intense temperature, radioactivity and perhaps pressure presented a substantial development problem and was carried out as Project 26.1.

PROGRAM 22—REACTION HISTORY

Project 22.1—Nuclear Radiation Measurements

This is a measurement of alpha versus time as a check on the performance of the device. The alpha alcove is shown in the previous figure. A number of detectors located here viewed the device through an 8-inch line of sight bore hole collimated to 6 inches, 20 feet in length.

Project 22.4—Technique Development Experiments

These measurements were of two types. First, an attempt was made to measure the shock time of arrival by embedding a number of barium titanate crystals in the tunnel wall nearest the device at known radial distances. Secondly, the early electromagnetic signal was measured in an attempt to relate it to the alpha of the device. For this

measurement the device room was lined with copper and three orthogonally aligned RF pick-up loops were installed.

PROGRAM 25—SHOCK GROWTH MEASUREMENTS

Project 25.1—Hydrodynamic Yield Measurements

This project was carried out by Armour Research Foundation under the direction of F. B. Porzel. The principal objective here was to measure the rate of shock growth in the rock. From this, the hydrodynamic energy and total yield can be obtained. The techniques of this experiment follow closely those used in the Armour Reseach Foundation blast measurements on the deep underwater shot, Operation Wigwam (see WT-1034). The tunnel figure shows the bore hole array used for these measurements.

2. EFFECTS MEASUREMENTS

PROGRAM 26—RAINIER EFFECTS MEASUREMENTS

The projects in this program were carried out with the following objectives:

a. To obtain samples of the radioactive debris for radiochemical yield determination.

b. To furnish information required for planning the safe containment of larger detonations in the same or other geological formations.

c. To furnish information required to reassure the public regarding the ground shock associated with underground bursts.

d. To furnish information required for effective use of nuclear weapons against underground targets or as demolition explosives.

e. To obtain samples for studies of geophysical significance.

f. To furnish information for estimating the amount of energy coupled into the seismic signal.

g. To obtain the post-shot space-time temperature distribution in the rock.

h. To obtain samples of occluded radioactive debris for analysis by collaborators in Project MICE.

The various agencies participating with UCRL in this program were: U. S. Geological Survey, Broadview Reseach Corporation, Sandia Corporation, Stanford Research Institute, Engineering Research and Development Laboratories, Edgerton, Germeshausen & Grier, U. S. Coast and Geodetic Survey.

ONE-POINT SAFETY TESTS

A problem closely related to the Rainier concept is that of carrying out one-point safety tests underground. The advantage here is again the containment of the radioactive debris. It is also possible that the recovery of the fissionable material by some kind of mining process may be feasible.

UCRL planned and carried out such a test in Operation Plumbbob (Saturn event). Two small tunnels of about 300 feet each were dug for this and future one-point shots concurrently with the digging of the Rainier tunnel. These tunnels were also equipped with blast doors. A wide range of alpha coverage was required for the Saturn event. This was accomplished by detectors located adjacent to the device, in an alcove off the device chamber, and in an alpha alcove similar to that shown in the figure. The Saturn event took place August 9. Project 22.1 and a few seismic stations associated with Program 26 participated in this event. Saturn was a success from the standpoint of containment, diagnostics and the performance of the device itself. The ground motions as measured by seismographs were significantly weaker than expected.

COSTS

Construction of the Rainier tunnel began on March 30, 1957, and was completed on August 5. The total amount of construction money spent in Area 12 was about one million dollars. This includes the cost of the tunnel and appurtenances as well as that of developing the site (e. g., roads, diagnostic building). The shot itself destroyed about one fourth of the tunnel. This corresponds to a non-recoverable cost in Area 12 of about 130,000 dollars. The average non-recoverable construction cost per tower shot in Area 2 including costs of tower construction, weather delays and shielding is about 650,00 dollars.

Due to the difference in yields and types of experiments performed in the two areas, these numbers probably should not be directly compared. However, it is certainly indicated that tunnel shots are probably significantly less expensive than highly instrumented tower shots.

Tunnel shots are more nearly analogous to balloon shots in that in both cases a small fraction of the initial investment is used up in each test. Tunnel shots probably could not compete with balloons on an economic basis alone, how-

Figure 2.19. Tunnel After Detonation.

ever, certain experiments, i. e., those requiring shields or close collimation, cannot be accomplished using balloons.

PRELIMINARY RAINIER RESULTS

The Rainier event took place September 19. The observer area was located 2½ miles from ground zero. The shock wave hitting the side of the hill was visible from the observer area. A ground wave was felt by a few observers. At later times a dust cloud rose several hundred feet caused by rocks rolling down the side of the mesa and the upslope wind. Ten minutes after the shot, the dust cloud had completely dissipated. Approximately one hour after the shot, an inspection party entered the tunnel and proceeded to the first blast door. Pressure gauges at the portal, monitoring the pressure behind each blast door, read less than 1 psi above atmospheric. Remote radiation detectors similarly located read less than 1 R/hr. No difficulty was experienced in proceeding to the second blast door by later inspection parties. Essentially no damage was observed up to this point (Station 11+00) but carbon monoxide levels were high ($\approx$500 ppm). The tunnel actually closed off at station 14+70. From station 11+00 up to this point the damage due to air shock and spalling increased gradually at first and then rapidly near the end. The radiation levels were and continue to read 0.02 – 0.04 mr/hr. This is identical to the pre-shot readings. Post-shot radiation levels on the mesa were identical with pre-shot readings.

All projects participating on the Rainier shot were generally successful. The measured alpha versus time curve was consistent with the expected values. As regards the critical question of yield measurements, a partial answer can be given at this date. The shock growth measurements of Armour Research Foundation were successful and preliminary analysis shows that the total yield can probably be obtained by this method to an accuracy of about 5 percent. The answer from the radiochemistry awaits the securing of a radiochemical sample. Drilling for these samples is in progress. Due to problems associated with the nature of this formation, the drilling is proceeding more slowly than anticipated.

The measurements made by the participating agencies in Program 26 have provided an abundance of ground motion data. One of the most striking results of these measurements is the unexpectedly weak seismic signals produced by Rainer.

CONCLUSIONS

The Rainier event was an experiment and as such answered some questions in a rather obvious way, provided data to answer more subtle questions and in turn raised new questions. Keeping in mind that as of this date the radio-chemical yield question is open, some of the more obvious conclusions from the Rainier shot can be enumerated as follows:

1. The underground testing of nuclear devices appears to be entirely feasible. The advantage of this method both politically and economically are particularly striking when compared to the costs and weather constraints associated with the highly instrumented tower shots in Operation Plumbbob.
2. From the standpoint of overburden and off-site ground shock damage, there appears to be no fundamental limitation on the testing of devices with yields up to 1 MT in Area 12, NTS.
3. The overburden on the Rainier shot was about two times that necessary to contain the explosion.
4. The damage radius in the tunnel was much smaller than expected.
5. The explosion sealed itself off much more effectively than expected.
6. Due to the small damage radius and effective sealing, future post-shot drilling for radiochemical samples will be done underground rather than from the top of the mesa.
7. With significantly higher yields underground tests can be useful tools in the study of the interior of the earth by means of world-wide recording of the seismic signals.

K. RADIOACTIVE DECONTAMINATION OF FORWARD AREAS

During the course of the Operation, several occasions arose in which decontamination measures were required in order to speed up re-entry into an area. Two distinctly different types of contamination, requiring different techniques of decontamination, resulted from the tower and balloon shots.

TOWER SITES

In general, contamination from the tower shots resulted primarily from on-site fallout of the tower debris. Fairly large areas were contaminated with the highest levels of activity observed in the immediate area of the tower

site. In those cases in which fallout produced the contamination, decontamination, when required, was accomplished quite simply by grading the area of importance and removing approximately 4 inches of dirt. The dirt thus removed was dumped into pits to dispose of it. This grading operation was highly successful in that it removed virtually all the radioactive material, leaving the area clean. In those cases in which alpha contamination was present, the grading operation proved to be quite satisfactory as a quick and easy method of decontaminating.

BALLOON SITES

The balloon shots posed an entirely different problem in decontamination. Repeated use of the same ground zero area for successive balloon shots required that the ground zero area itself be re-entered and decontaminated. This was a problem not encountered in any of the tower shots. The balloon shots produced no significant on-site fallout.

The main contributing factor associated with contamination near balloon sites was neutron-induced activity in the soil. The most significant contaminant was Sodium 24, which has a half-life of approximately 14.9 hours. In general, early time contamination (H + 6 hours) was in excess of 100 R per hour. Fortunately, since the predominant activity was the Sodium 24, a fairly accurate forecast of the contamination levels on succeeding days could be made. This allowed ample time in which decontamination measures could be planned. Long-lived activity induced in the soil was usually predominant by the time the total activity was of the order of 100 mr/hr. It was at this level that decontamination measures were, in general, instituted.

Due to the fact that the contamination was largely a result of neutron-induced activity in the soil, the normal grading and scraping methods were not appropriate ones to use for the following reasons: removal of 18 to 24 inches of soil after each balloon shot was prohibitive if for no other reason than the fact that signal cables would soon be exposed and damaged. Therefore, in order to decontaminate the balloon areas, clean dirt was hauled in and placed on top of the contaminated soil. In effect, decontamination was accomplished by laying down sufficient shielding to reduce the radiation to acceptable levels. The usual practice was to lay down approximately 8 to 12 inches of clean dirt in the area of interest, the amount depending on the activity levels at the time decontamination measures were instituted.

Of primary importance in these decontamination procedures was the "greenhouse" pad, the area in which preparatory work was accomplished on the device to be fired. Normal work time in the "greenhouse" area was approximately 50 hours, so a radiation level less than 10 mr/hr was desirable in this area. In general, this level was achieved; however, in some cases as much as 24 inches of dirt was required to accomplish this.

EXPERIMENT TO REDUCE THE NEUTRON-INDUCED ACTIVATION PROBLEM

An experiment that might be termed a prophylactic measure was devised.

The principal reason for the existence of radiation of relatively long duration after an atomic explosion at the Nevada Test Site seems to be due to the formation of Na^{24} by slow neutron capture in Na^{23} present in the soil. Since most of the neutrons yielded by a nuclear device are fast, they must be moderated in the soil before being captured. They probably penetrate to a considerable depth in the soil before they are thermalized; afterward perhaps of the order of half return to the surface where they activate the Na^{23}.

This experiment consisted of using colemanite ($Ca_2\ B_6\ O_{11} \cdot 5\ H_2O$) mixed with various amounts of road mix.

Colemanite has an extremely high capture cross section for thermal neutrons due to the present of B^{10} which is present to about 20 percent in naturally occurring boron. The capture cross section for fast neutrons is, however, quite small and for this reason colemanite is not useful for capturing neutrons before moderation.

A possible method for using colemanite is to mix it with a binder such as road mix, in proportions such that if a layer of this mixture is placed on the surface of the ground, it will itself be free of Na^{24} activity, due to the preponderance of slow neutron captives in the boron, and at the same time it will act as a radiation shield to attenuate the gamma radiation from the Na^{24} atoms decaying in the soil underneath.

The principal constituents of NTS soil in Area 9 are roughly given in the following table:

Si	-	30%
Al	-	8%
Ca	-	3%
Fe	-	1%
0	-	54%
Na	-	2%
K	-	3%

It is conceivable that some of the Na^{24} is due to the reaction

$$n^1 + Al^{27} \rightarrow He^4 + Na^{24}$$

However, the cross section is quite small (110 millibarns) even for neutrons of energy 14 Mev.

The mean free path of a 14 Mev. neutron in NTS soil is about 10 cm., perhaps slightly less. It is roughly this same length in colemanite or in a mixture of colemanite and NTS soil or in a mixture of colemanite and road mix.

These figures show that it is useless to consider the idea of capturing the neutrons in a boron rich layer at the surface before they are slowed down.

The mean free path of a thermal neutron in pure colemanite is about 0.05 cm. Thus, if this material is mixed with NTS soil or road mix in equal proportions, the mean free path will be about 0.1 cm. for a mixture of density 2. A layer of this material placed on the surface of the ground should be almost completely free of Na^{24} activity.

A colemanite pad of this composition was tested in conjunction with the firing of Hood on July 5 and Owens on July 25. Its thickness was chosen to be approximately 1 foot. This figure represents about 2½ mean free paths for a 2.8 Mev. gamma ray. Thus the pad was expected to reduce the radiation level at its center and at ground level (to eliminate edge effects) by a factor of 10. The pad was 64 feet square and its center was located 135 feet from ground zero. Measurements of the radiation level at the center of the pad when compared with those made at points equidistant from ground zero but off the pad, at first showed a ratio of 5. When the pad was swept with a vacuum cleaner, this ratio rose to the expected factor. The pad was not visibly damaged by the blast.

Since this experiment seemed to be successful a second one was planned in which a much higher reduction was expected. The colemanite fraction of the mixture was reduced from one-half to one-quarter since the first pad seemed unnecessarily rich in colemanite. The thickness of the pad was increased to 2 feet and a radiation level reduction factor of the size of 50 was expected. The new pad was located approximately 150 feet from ground zero. It was tested in conjunction with the firing of Wheeler on September 6, but its performance was highly disappointing since the reduction factor proved to be only 5. Why it did not perform as expected is as yet unclear. This may be due to the fact that the neutrons from Wheeler were those associated with a pure fission spectrum and/or the fact that the pad was not rich enough in boron.

While no really useful pad has been designed as yet, the results are sufficiently interesting to warrant further investigation into the use of colemanite. Such tests should perhaps be made on a small scale in the laboratory, rather than in the field.

L. SUPPORT — SANDIA CORPORATION

Projects which supplied Sandia Corporation support to the Test Director's organization were grouped under Program 64.

Project 64.1 dealt with the balloon suspension system and has been previously described in New Test Techniques - Balloons (Chapter II).

PROJECT 64.2 - HIGH TIME RESOLUTION TELEMETRY

Project 64.2 made high time resolution measurements on every test event on Plumbbob with the exceptions of La Place, John, Saturn, and Rainier. In addition, project personnel supplied, installed, and operated release tone equipment on the John event. A fiducial time marker system was also installed and operated on some UCRL events.

Project 64.4 had responsibility for balloon cabs and has been reviewed earlier in Chapter II.

The Sandia Test Group was administratively responsibile for project personnel on Projects 1.5 (DOD), 30.4 (CETG), 34.1 (CETG), and 26.4B (UCRL). The Arming and Timing Group which reported technically to the Test Director and the Blast Prediction Group which reported technically to the Test Manager, were also administered by the Sandia Test Group.

M. SUPPORT —EDGERTON, GERMESHAUSEN & GRIER, INC.

INTRODUCTION

Edgerton, Germeshausen and Grier, Inc. (EG&G) participated in all 30 shots detonated at the Nevada Test Site during Operation Plumbbob.

Assignments, approved by the AEC, consisted of providing the following services: timing and firing, scientific photography, alpha and other radiation measurements, and analysis. Work was performed for tower, balloon, underground, rocket, and single-point shots. These tasks were sponsored by LASL, UCRL, DOD and CETG. Other tasks were sponsored by AEC, Sandia Corporation, Holmes & Narver, and the Lovelace Foundation.

Several new techniques and equipment were proved out successfully by EG&G on Plumbbob. Equipment modified to meet requirements for greater sensitivity and flexibility also proved satisfactory. Of particular note, final Fireball and Alpha reports were issued to participating agencies within a few days after each shot through the use of newly acquired computing equipment.

This section discusses EG&G Support in general terms only; a detailed technical report will be issued at a later date as a Weapons Test Report.

EG&G SUPPORT PARTICIPATION

1. TIMING AND FIRING

Timing and firing objectives were to provide users independent timing systems when needed, signal distribution systems, timing signals, firing systems and equipment for voice countdown and dry runs; to provide personnel for the Arming and Firing parties; to telemeter, indicate, and record meterological data; to measure and record time of detonation (to an accuracy of ± 1 msec with respect to WWV); to measure and record time of flight for air-to-air missiles; and to provide Bhangmeters for quick yield data.

The T/F system was capable of firing any one or all of three possible shots simultaneously;

Figure 2-20. EG&G Alpha Station.

at times there was in addition a capability for one or two single-point shots. Dry run capability was maintained on a 24-hour, 7-day-a-week basis. Ready requirements were met for balloon and tower shots which were scheduled at the same time. Timing signals were furnished to experimenters both by hardwire and by radio.

Special signals to control gas filling operations were an added requirement. Individual shot requirements made it necessary to provide 7 special signals; signal distribution stations handled as many as 192 local signals. Independent timing systems were established for the TG57 Project in Area 13, for 4 LASL single-point shots in Area 3, and for 2 UCRL underground shots in Area 12. Additional monitoring circuits were required to indicate at the CP readiness for all devices.

As in previous operations, EG&G provided television circuits for telemetering some of the critical, optical experiments back to the control area. This equipment operated reliably.

2. PHOTOGRAPHY

Photographic commitments were to record the visible phenomena resulting from detonations, which data was reduced and interpreted by the EG&G Analysis Group. Major tasks were to photograph fireball growth for yield, growth and motion of the atomic cloud after shock breakaway, and position of burst for the air-to-air missile (shot John). Photographs were also made of ground and airborne structures to determine effects of blast and thermal radiation for DOD and CETG. Photographic work was accomplished by using both motion picture and still cameras which were operated from fixed stations, mobile-trucks, trailers, and jeeps, and from aircraft. Backup stations were used for all shots in the event of camera malfunction or gross disagreement among close-in cameras. A total of 33 stations were needed for Plumbbob coverage. Film, which on the average was recovered by H+3 hours, was processed at the Las Vegas EG&G laboratory. Transportation from the Site was by auto or aircraft, as circumstances permitted.

3. ALPHA AND OTHER RADIATION MEASUREMENTS

The Alpha Group performed reaction history measurements on all 13 devices detonated as part of the LASL test program. In addition, radiation dosimetry was undertaken for CETG.

As more sensitive components were needed to record this information, EG&G designed and produced a simplified recording system which reduced the total amount of equipment needed at each channel of information. The system operated successfully. The standard Rossi-type system was basic to all recorder instrumentation; linear scopes were used as experiments dictated.

During the test, 5 alpha blockhouses were maintained, as well as 12 detector stations, and 1 tower detector location.

Film badge dosimetry measurements were made for CETG. These measurements were to measure prompt gamma radiation at various locations in shelters, and at various distances from ground zero. Dosimetry work was also done for the DOD, and under CETG sponsorship for the French and German Governments (NATO), and Holmes & Narver. Placing of badges, recovery calibration, processing and analysis, all were performed by EG&G.

Assistance was rendered to the Oak Ridge National Laboratory, working under CETG sponsorship to obtain dosimetric measurements of neutron flux.

4. ANALYSIS

Major analysis work consisted of reading films, reducing data, and issuing for each shot final Fireball and Alpha reports (where applicable) which were completed within a few days after each detonation. Preliminary reports (based on reading one film) gave the preliminary yield number to all participating agencies at approximately H + 4 hours for each shot. Final reports consisted of complete coverage of the visible and nuclear phenomena. Projection motion picture prints were also made available to users as an aid to visual interpretation of the nuclear phenomena.

5. MISCELLANEOUS SUPPORT

In addition to the various technical support services rendered, EG&G staffed the S-1 function of the Test Director's Staff, and operated the CP Machine Shop. For the Test Manager, EG&G operated new fallout prediction units designed by the National Bureau of Standards. Also representing the Test Manager, two members of the Las Vegas laboratory conducted briefing talks for official visitors, outlining the objectives of Operation Plumbbob and describing means of meeting these objectives.

NEW INSTRUMENTATION AND TECHNIQUES

Much of the equipment used by EG&G on Plumbbob was of new design, or was modified for more flexibility and sensitivity. New instrumentation and techniques used by each group is described briefly.

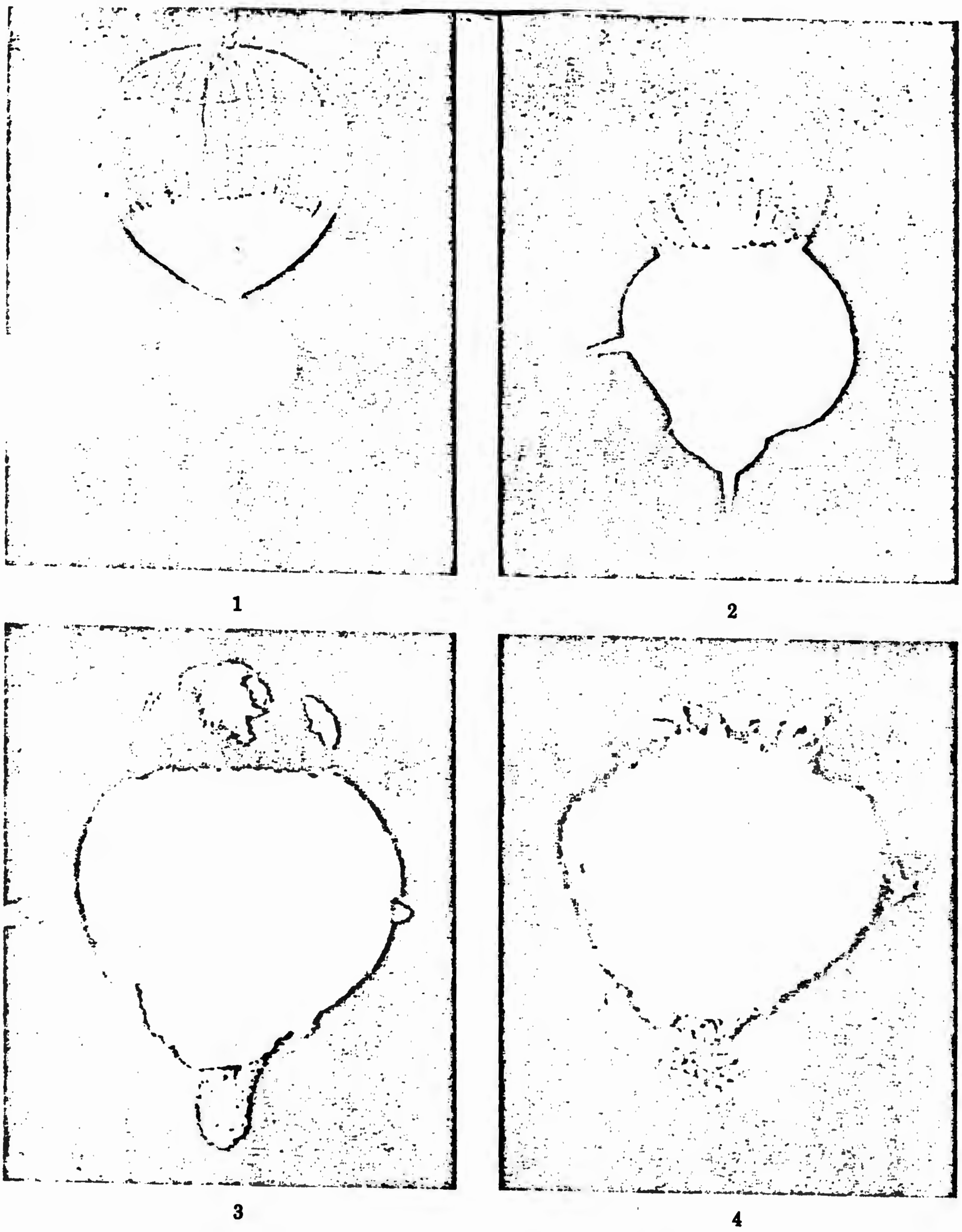


Figure 2-21. EG&G Fireball Photography — Shot Wheeler.
Rapatronic Camera Series.

1. TIMING AND FIRING

The Airdrop Sequence Timer (an electromechanical timer) was designed for coverage of the missile shot. The short time-of-flight of the missile made it necessary to have a more flexible timer; also the need for concurrent dry runs of missile and tower shots made it necessary to design the new timer.

A new fiducial marker, designed for photographic use, proved to be more reliable, easier to transport, install and aim.

Equipment was developed for telemetering weather information from the area to outlying points and to the CP.

2. PHOTOGRAPHY

The Image Converter Streak camera was proved out satisfactorily at NTS. This camera, which records fast transients, is smaller and therefore more portable than other cameras of this type which have been used in the past.

Three new Aximuth-Elevation mounts were purchased for DOD high elevation triangulation work on Plumbbob. These mounts proved to be more accurate and flexible than was the theodolite equipment which had been used for the same purpose. The mounts were used on the John and Owens shots.

New Rapatronic cameras, lighter, more compact, and easier to operate and maintain, were used satisfactorily on the tests.

3. ALPHA

A simplified and more sensitive alpha system, designed and produced by EG&G, was used successfully on shots in Areas 3 and 7. This X-1 two-scope system reduced the total amount of equipment needed at each channel of information. The new EG&G scope and photo cell detector are an integral part of the new system, which incorporates an automatic time-tie and is capable of greater dynamic range than that of the present standard system since an attenuator is used between the two scopes.

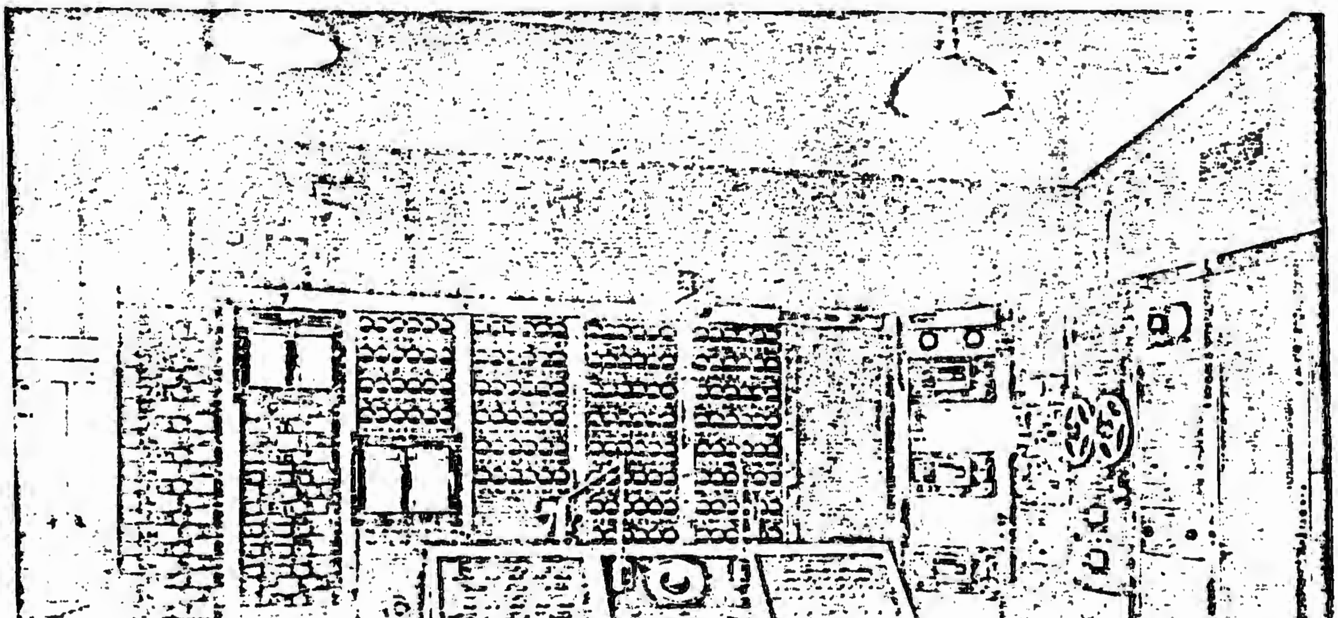


Figure 2-22. Control Room Timing and Firing Equipment.

4. ANALYSIS

Application of new techniques and electronic computing for film reading permitted the Analysis Group's rapid issuance of final Fireball and Alpha reports. Equipment used was a new EG&G system incorporating a velocity-mark reader, which took both 16-mm and 35-mm film, a digitizer, a computer, and automatic printers, plotters and comparators. A new Fireball reader developed by EG&G also proved highly successful.

PROBLEM AREAS

From the standpoint of EG&G, the main problems encountered during Plumbbob stemmed from multiple capability requirements beyond estimates, and the accelerated shot schedule.

1. MULTIPLE CAPABILITY

Although the Timing and Firing system was made more flexible to meet Plumbbob requirements, increased flexibility was asked during the tests. Special signals were needed to control gas-filling operations on almost all shots and monitoring requirements became very severe. Although a number of spare circuits were provided in the sequence timer, these were used up quickly and it was necessary to improvise modifications to the equipment in the field. Monitoring circuit needs for telemetering device readiness to the CP were also somewhat beyond anticipated requirements. The number of critical experiments to be interlocked in the firing circuit was at times greater than ever before, requiring that new equipment be developed and installed. The same readiness date for tower and balloon shots proved to be an added burden for an already overtaxed Timing and Firing system.

2. ACCELERATED SHOT SCHEDULES

Pre-operation shot schedules presumed shorter intervals between shots than heretofor achieved. Although it is recognized that this resulted in a more economical test series, EG&G was pressed to make rapid equipment shifts from area to area without subjecting available personnel to fatigue, thereby losing reliability. Although this difficulty was anticipated, available time and limited contract funds precluded expanding the technical staff and the equipment to accommodate the increased tempo of the series.

Similar to the problem noted above, the extreme dry-run schedule, day and night, 7 days a week, proved a serious problem to all EG&G groups. There were as many as 10 dry runs in one day. These, and last minute shot postponements resulted in near fatigue of personnel on occasion. Like personnel fatigue, late technical changes and salvage operations must be carefully weighed to assess their effect on reliability.

The overall economical justification for the accelerated program is clear, but the problems introduced thereby should also be acknowledged. Funds will have to be made available for an expanded staff if future operations are to be conducted without jeopardizing reliability.

N. SUPPORT — ARMING AND FIRING

The Arming Organization was responsible to the Test Director for arming and disarming the nuclear weapons and devices. Other associated responsibilities were the overall reliability of the components required for arming and firing the device, and safety in relation to accidental firing of the device or weapon after installation at the zero area. In order to fulfill these obligations, the Arming Organization worked in close liaison with LASL, UCRL, EG&G, SC and DOD.

The Arming work was divided into the following parts: Pre-dry Run Tests, Zero Area Installations, Dry Runs, Interlock checks, Monitor checks, Arming and Disarming.

1. The Pre-Dry Run compatibility checks were jointly conducted at the Sandia Security Compound with a representative from each organization concerned. These tests included visual inspection, voltage and resistance measurements, high voltage output adjustment, interlock settings and functional operation of the Zero Rack, and cabling as connected in the final shot arrangement. At the conclusion of these tests the equipment was ready for installation and dry-running at the zero area.

2. The Arm-Fire components were installed at the zero areas by the organizations responsible; at completion, the Arming personnel operated the equipment locally, if required for test purposes prior to regular dry runs. This provided an opportunity for the High Time Resolution Telemetry to make neutron output rate and time measurements, and the diagnostic project to adjust oscilloscope and detector sensitivities. In addition, numerous other checks were jointly performed with organizations concerned on Zero Racks, AC power, DC power, battery chargers, interlocks, monitors, signal lines, etc.

Page 72 deleted

3. Dry runs were conducted in order to check that equipment operated properly while connected in the same manner as at shot time. There were 4 different type runs conducted: Regular, Power, Frequency and Hot Run. On a Regular Run timing signals were available to all experimenters but participation of users was voluntary based on a need to run. The Power Run was mandatory for all experimenters and established that sufficient power would be available at zero time. The Frequency Run was mandatory and proved that all experiments operated successfully free from RF interference. The Hot Run provided the weapons people a chance to test the gas plumbing and live pit under simulated shot pressures. In some cases when time was limited, two or more of these specific runs were conducted simultaneously. During all runs the arm-fire components at the zero area and the interlock and monitor indications at the control point were carefully observed by an Arming representative for proper operation.

4. All shots contained interlocks in the gas, arm, or fire signal lines. After a sufficient number of dry runs had been conducted to assure that all equipment was operating successfully, interlocks were individually checked in a "go" and "no-go" position. These tests on some shots were quite complicated and involved as each experimenter with equipment controlling an interlock had to be present at his station while two operators were on hand at the Control Room. A man had to be present at the timing distribution station, the signal pit, and at the zero area and communications were necessary at all locations in order to supply the necessary instructions as the interlock checks progressed. The usual procedure was to get all interlocks in a "go" position and send out a signal to prove continuity in the signal line under check. Next, an individual interlock was disabled while all others were in a "go" position and the signal was again sent out from the control room thereby confirming that the disabled interlock prevented the arrival of the fire signal at the zero area. All interlocks were checked in this manner.

5. All shots had one or more monitors with indications displayed at the control room. These monitors were not automatically interlocked in the critical signal lines but the equipment monitored was considered sufficiently important to cancel a shot if a malfunction was indicated. All monitors were carefully checked in a "go" and "no-go" position for the proper indication.

6. Arming operations consisted of making final checks and connections to the device and associated equipment preparatory to firing. All arming activities were carefully performed with the aid of check sheets which thoroughly enumerated each operation. Progress of the Arming Party was reported by radio to S-3 at specified check points. Final arm connections were completed as close to zero time as practical and only with permission from the Test Director or Associate. This allowed experimenters the maximum time to secure stations and vacate the forward area. It also gave the weather panel an opportunity to evaluate data obtained closer to shot time thereby minimizing the chance of disarming due to changing weather conditions. The Arming Party was composed of personnel from several organizations with each having specific responsibilities in relation to arm-fire components, device or associated experiments. The Arming Party assembled at the control point where the monitors were carefully observed to verify that the arm-fire equipment was in a safe or normal condition. From the control point the Arming Party proceeded to the timing distribution station and the arm-fire monitors were again checked for proper indication. At the conclusion of the checks in the timing distribution station the Arming Party opened the DC signal power switch before starting to the zero area. At the zero area specific voltage and resistance checks were performed on the arm-fire equipment. The measurements were compared with readings taken previously in order to assure that the arm-fire equipment was in normal condition electrically. The arm-fire equipment was also visually checked for mechanical readiness or damage. At the completion of the electrical and mechanical checks the Test Director was called to obtain permission to complete the final cable connections and ready the gas injection rack. The final connections and preparations were never made until the Test Director was sure the forward area was clear of people not required during or following arming.

After the arming operations were complete at the zero area, the Salvage Party started to work. On tower shots the elevator hoist and power transformer were removed. On balloon shots the Greenhouse Bridge Crane and AC power generator were salvaged before Arming. At completion of the salvage operation, both Arming and Salvage Parties along with the security inspectors evacuated the zero area and proceeded toward the control point area. The Arming Party stopped at the timing distribution station on the way to the control point and placed

it in a state of readiness for the shot. At the control room the Arming Party made final monitor checks to assure that the weapon or device was ready to be fired and then reported to the Test Director.

7. The disarming procedure was essentially the reversal of the arming but without the exhaustive checks that were completed before arming. Disarming was accomplished during Operation Plumbbob for three separate sets of conditions. These included normal or routine disarming accompanying a weather delay, disarming due to delay caused by technical difficulties, and disarming following a "misfire."

   a. Routine disarming was performed when the device had been armed and the shot was postponed because of unsuitable weather. Disarming was necessary before normal activity could be resumed in the forward area. A considerable delay sometimes resulted because of the replacement time for salvaged tower equipment; especially the elevator hoist, elevator controls, and utility power transformer. The disarming team consisted of Arming personnel, EG&G representatives, and gas-fill representatives when that equipment was involved on the test. The DC signal power was shut off at both the control point and the distribution station until the disarming was completed. When the elevator equipment was replaced and in operation, the disarming team went up the tower and removed patch cables, disconnected detonators, shut off gas-fill valves, and any other operations necessary to put the device and its associated equipment in a safe condition.

   The normal or routine disarming function was accomplished at least once on most towers and several times on some that were delayed for long periods after their first ready date. There was one balloon shot, Charleston, where disarming of a routine nature was necessary due to a weather delay. This disarmament was accomplished essentially the same as on towers except without requiring the salvaged equipment to be replaced before disarming could proceed.

   b. Disarming due to technical difficulty was performed once during the operation when the firing of Whitney was stopped [redacted] The type of disarming procedure followed in this case was very similar to that used for a routine disarmament, but consideration had to be given to the probable cause of the failure and possible consequences.

   c. Disarming due to a "misfire" had to be accomplished once during the operation when Diablo failed to fire at the completion of the timing sequence. A meeting was called immediately by the Test Director to discuss the cause of the failure. It was apparent from the monitor indications that AC power was not available to the zero rack or was of a very low value. Because of the indication that AC power was removed by salvage of the hoist and utility transformer, it was deemed safer to climb the tower and complete disarming before reinstallation of the elevator equipment. The Disarming Team delayed going to the zero area until monitors at the timing distribution station were checked and found to agree with the indications at the control point. At the zero area an Arming representative, [redacted] representative, and a device representative proceeded to climb the tower while another device representative and a EG&G representative remained at the base. The Disarming Team [redacted] and a multimeter up the tower while air-breathing apparatus was available at the base of the tower if needed. The cab was carefully surveyed and was found clear of contamination. The patch cables were removed, the detonator cables were disconnected, the "pin" monitor power supply disconnected [redacted]

   No AC power was found in the cab and later checks of the power circuitry showed that the zero rack had been inadvertently connected to "utility" power rather than "instrument"

power and so was disconnected when the utility transformer was salvaged. On all subsequent shots, instrumentation AC power monitors were installed at the control point in order to prevent any further "misfire" due to loss of AC power. Also, the utility power was disconnected at the base of the tower during the Power Run in order to prove that the firing system was operating from instrumentation power.

Safety in relation to accidental firing was considered a grave responsibility by the Arming Organization because numerous dry runs were conducted after installation of the live device or weapon at the zero area. In respect to the danger this situation offered, an arming man was present during dry runs to assure that the live detonator cables were grounded or safely isolated.

During Operation Plumbbob, an MB-1 missile containing a nuclear warhead was fired over the NTS from an F89D. The MB-1 was assembled and checked at Indian Springs Air Force Base by Air Force Personnel; however, an Arming representative of the Test Director closely monitored the handling and checkout procedures to assure readiness and accepted safety practices in relation to the nuclear warhead.

The Arming Organization completed Data Books on each shot during Operation Plumbbob which contain the actual check lists that were used in each phase of the Arming work. The books will be given to the Test Director after documentation and will be available for reference in the Operation Plumbbob files.

Looking back and evaluating the experience gained during Operation Plumbbob, the following recommendations are presented:

1. There should be a separate cable and associated terminal boxes to supply the critical signal lines needed to arm and fire the weapons or devices. This signal cable should contain sufficient lines to dry run several areas at one time.

2. In consideration of reliability, a shot schedule should never be accelerated to the point where personnel do not have adequate time to properly set up and check equipment a sufficient number of times to establish confidence.

3. If at all possible the traffic at the zero sites should be reduced. This applies to working personnel as well as visitors, especially during initial set up and dry runs. At times the work at the zero sites was hampered due to crowded conditions.

4. All zero sites should have a minimum of two telephones. There were several shots where communication by telephone was inadequate.

5. In future tunnel tests more space should be supplied at ground zero for installation of equipment and standing room for associated personnel.

6. On future balloon tests it is recommended that a study be made by cable experts on the suitability of the present cable clamp used to support the balloon signal cable, and a better system should be devised to protect the balloon signal cable from vehicle traffic.

O. OUTSIDE SUPPORT

Outside support for Operation Plumbbob was provided principally by two agencies—Holmes & Narver, Inc., as the architect-engineer, and Reynolds Electrical & Engineering Co., Inc., as the maintenance, construction and field support contractor. Holmes & Narver's function was to supply required design, establish construction schedules, conduct field inspections, and administer contracts of the lump sum contractors. Reynolds' function was to operate and maintain the camp and other permanent test site facilities, perform construction that could not practically be done by lump sum contractors, and to provide field support required by various using agencies. As an added task, Reynolds established a Rad-Safe organization to provide monitoring services and film badge analysis. In addition to Holmes & Narver and Reynolds, several lump sum contractors and one CPFF contractor undertook construction contracts before and during the Operation. These contractors performed construction on towers, tunnels, wells and miscellaneous structures.

Based on the problems experienced during the operation, primarily that of meeting schedules, the following recommendations are worth noting:

1. An attempt should be made to eliminate the duplication of paper work between the architect-engineer and the maintenance contractor in order to minimize construction delays.

2. The use of lump sum contractors after the start of the operation should be

avoided because of the lack of time control that can be exercised on this type of contract.

3. All lump sum and CPFF contracts should be awarded and administered by test site personnel in order to assure appropriate control.

4. Field inspection forces of the architect-engineer should be expanded to a level commensurate with the construction activity at the site.

The above recommendations all point toward enhancing chances of meeting critical schedules. It should be noted, however, that despite the problems implied in these recommendations both Holmes & Narver and Reynolds extended maximum effort to successfully meet nearly all scheduled requirements.

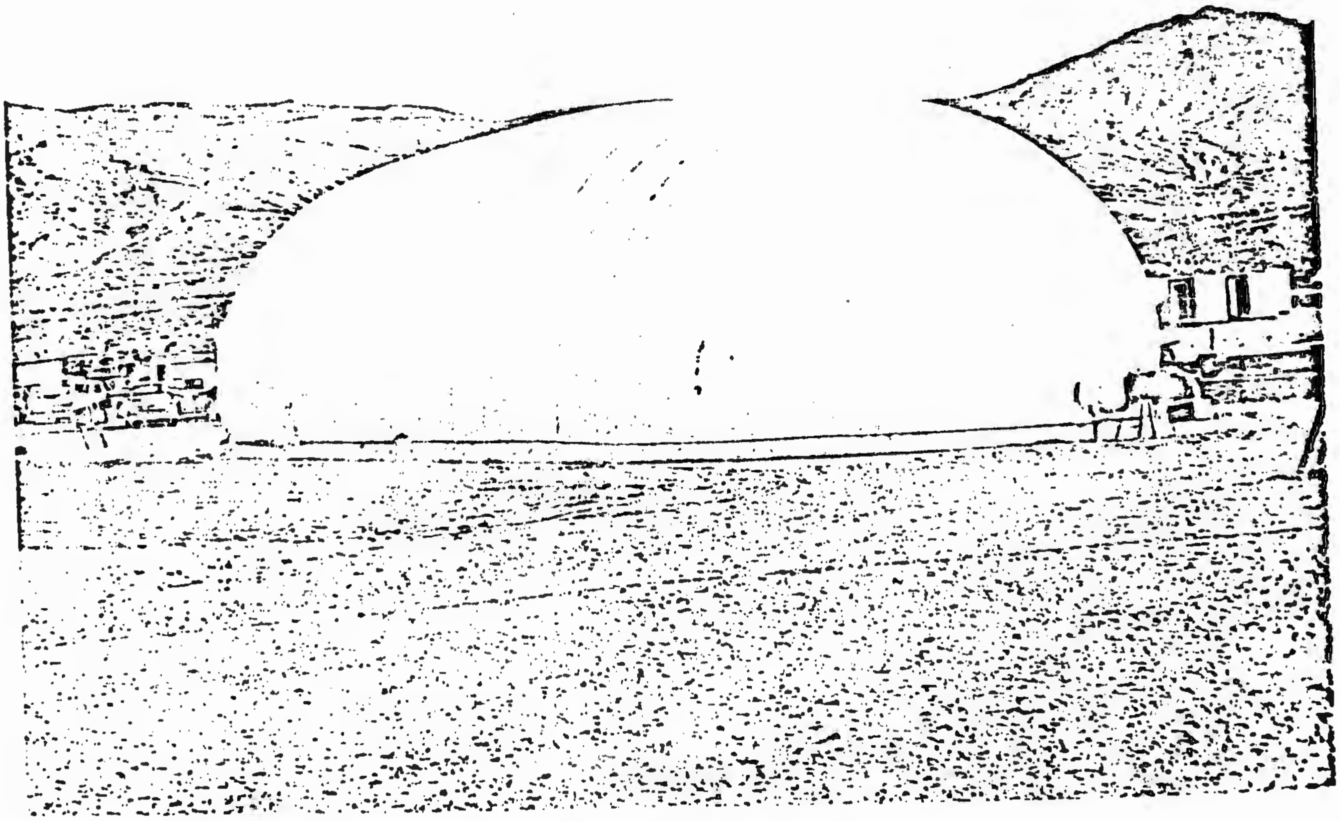


Figure 2-24. Inflatable Warehouse — Camp Mercury.

CHAPTER III

ADMINISTRATIVE OPERATIONS

A. OFFICE OF THE TEST DIRECTOR

The Test Director was appointed by the Atomic Energy Commission and given general responsibility for the coordination and scientific support of the scientific test program, for the conduct of the experiments, and for collecting and evaluating data acquired from the tests.

The Test Director discharged the above overall responsibility by coordinating the efforts of the six Test Groups in the field. These Test Groups, through their Test Group Directors, were responsible for the entire scientific test program. The Test Director became involved in operational details only when resolution of inter-agency problems was required, and when he directed, through his staff, the coordination of schedules and detailed movements of all agency personnel near shot time.

To asist him in the discharge of his responsibilities, The Test Director appointed an Associate Test Director, Mr. Don Shuster to act for him in his absence, and a Staff Co-ordinator who was responsible for organizing the Test Director's staff sections and implementing the Test Director's policies through the staff sections.

B. MILITARY ASSISTANT TO THE TEST DIRECTOR

Acquisition of maximum experience from each shot is a fixed goal in all test series. This policy brings many diverse groups together in a common effort. The AEC laboratories develop new weapons. The military laboratories examine weapons effects. The Air Force operates cloud sampling aircraft, utility helicopters, logistic cargo flights, fires air-delivered weapons, and orients crews by flying them near the detonations. The Navy and the Army likewise participate heavily in the weapons effects tests. Both the Marines and the Army conduct troop exercises. All services bring large numbers of trainees and observers of all descriptions to obtain experience in operating under the conditions of nuclear detonations.

These diverse groups divide into two major categories—civilian and military. The mutual understanding which is essential to success is assisted by integrating civilian and military personnel throughout the test organization. On Plumbbob one step in this integration not made in previous series was the appointment of a Military Assistant to the Test Director. The function of this officer was to participate informally in the Test Director's policy discussions in the interest of mutual understanding among civilian and military personnel.

Within the Test Director's organization, the Military Assistant assumed the additional duty of approving the Desert Rock plans for the Test Director to assure minimum interference with scientific programs and to provide maximum practical latitude for accomplishment of the Desert Rock objectives.

The Military Assistant avoided any tendency to operate as an additional operating headquarters between the Test Director and the Director of the DOD Test Group. He did assist in communication between these two Directors and also with the Military Deputy Test Manager.

Plumbbob experience in the integration of of the wide variety of activities into the common effort necessary for maximum utilization of active material leads to the following comments:

The present philosophy of firing specific weapons effects shots according to established requirements of the weapons effects program yielded highly significant effects data and materially reduced effects experiment participation on weapons development shots.

Nevertheless, to realize maximum utilization of active material and to permit completion of the effects program, the DOD Test Group participated on practically all major shots with the understanding that the interests of the effects experiments yielded in an emergency to the requirements of weapons development. No significant interference with the weapons development program arose from the weapons effect program and, furthermore, all the major objectives of the weapons effects program were met.

Tactical development for nuclear warfare requires participation on actual detonations by

troop units. These range in size and complexity from small flights of aircraft flying by in the vicinity of the burst up to fairly large combined arms field exercises. There were two field exercises conducted during Plumbbob. A Marine air landing exercise was conducted on shot Hood and an Army air landing assault was conducted on shot Smoky. Approximately one month prior to the initial ready date for Smoky the Test Director learned that it would be technically possible to advance the initial ready date by two weeks. Because of the fact that the field exercise could not be advanced at all, this advance was not made. It is possible that as the size and flexibility of the national stockpile of nuclear weapons increases, the need for tactical development may increase to the point where it is equally critical with the need for development of new weapons. In such a case, scheduling of shots of reliable high air burst stockpile weapons for purely tactical development purposes should be considered for the then current test series.

Shot John, the air-to-air rocket, was fired by the Air Support Group, including the arming of the device. Preliminary conferences between the Test Director and the Commanding Officer of the Air Support Group provided an advisory system to the military from the regular AEC arming personnel which considerably reassured both parties and eliminated operational interference during the final critical positioning orbits of the delivery aircraft. A similar philosophy in future firings by the military would probably realize similar benefits in increased reliability and in increased proficiency of the military in the support activities incident to a nuclear firing.

Two technical projects conducted by Desert Rock developed into investigations that would probably have been better established as AFSWP projects under the DOD Test Group. They were Project 50.3, conducted by the Evans Signal Laboratory, and Project 50.8, conducted by the Army Artillery and Guided Missile Center. Both of these projects had the objectives of locating ground zero, estimating yield, measuring cloud height, predicting and tracking cloud travel, and predicting and measuring fall-out. This is a highly technical objective. The technical direction of the DOD Test Group would have been of assistance, had this been made an AFSWP responsibility.

C. ADMINISTRATIVE SERVICES (S-1)

The S-1 staff for the Test Director was formed in October 1956 from personnel of EG&G. Initially the section was located in Livermore with subsequent moves to Las Vegas in February and finally to Mercury in March 1957.

The basic responsibilities of this Section were to coordinate the administrative services type of requirement for all elements of the Test Director's organization. S-1 handled personnel housing; office, laboratory, and warehouse space; office furniture; communications equipment; mail; and recreation.

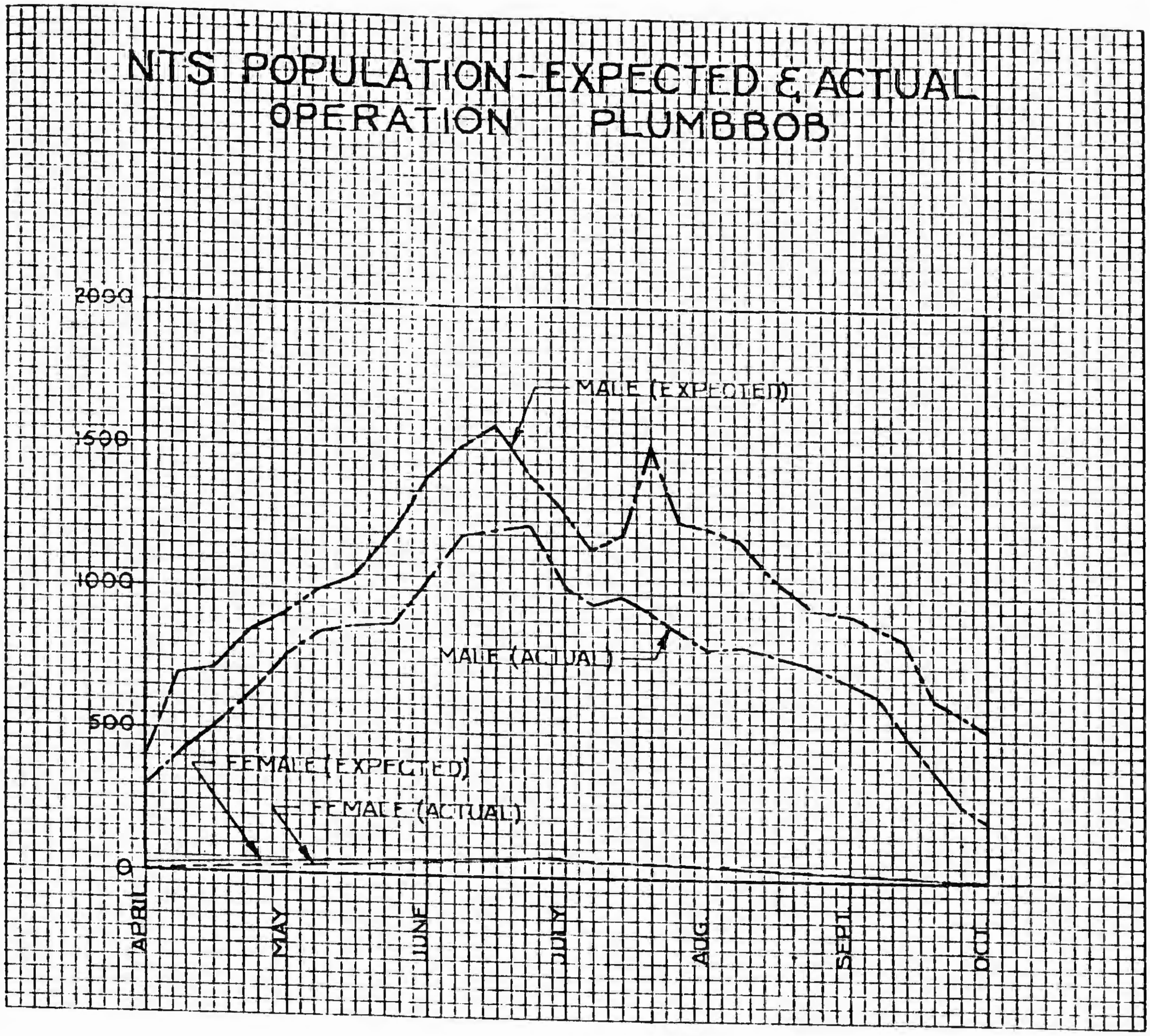
Information on requirements for the above items was collected from the Test Director's organization via the Status Reports, integrated and passed to the AEC for action.

It was the policy of the Test Director that S-1 would not be concerned with detailed problems within a Test Group, but would work with the "1" representatives of all groups to resolve general problems. Allocations of housing, space, vehicles, etc., were made to the Test Group in blocks for further detailed allocation within their own organizations.

HOUSING

As the first requirements for housing were compiled, it became evident that living accommodations during the Operation would be extremely tight. Due to the difficulty the laboratories experience in getting scientific personnel to participate in test operations, it was felt that the crowding and sub-standard living accommodations which obtained during the last operation should not be repeated. Statistics of anticipated population were presented to the Test Manager along with the Test Director's recommendation for improved living conditions. As a result of several meetings, the Test Manager augmented the existing housing units with the lease of a number of house trailers, 150 of which were allocated to the Test Director's organization. With a predicted Test Director population of 1600, the total housing space available to the Test Director is shown in the following table:

Type Housing	Number Assigned	Space Available
Letter series dormitories	9	450
"500" series dormitories	10	540
Trailers	150	450
	Total	1440



As the Operation progressed it became apparent that the population of Test Director personnel was falling below the anticipated levels as shown on the Status Reports. (See graph)

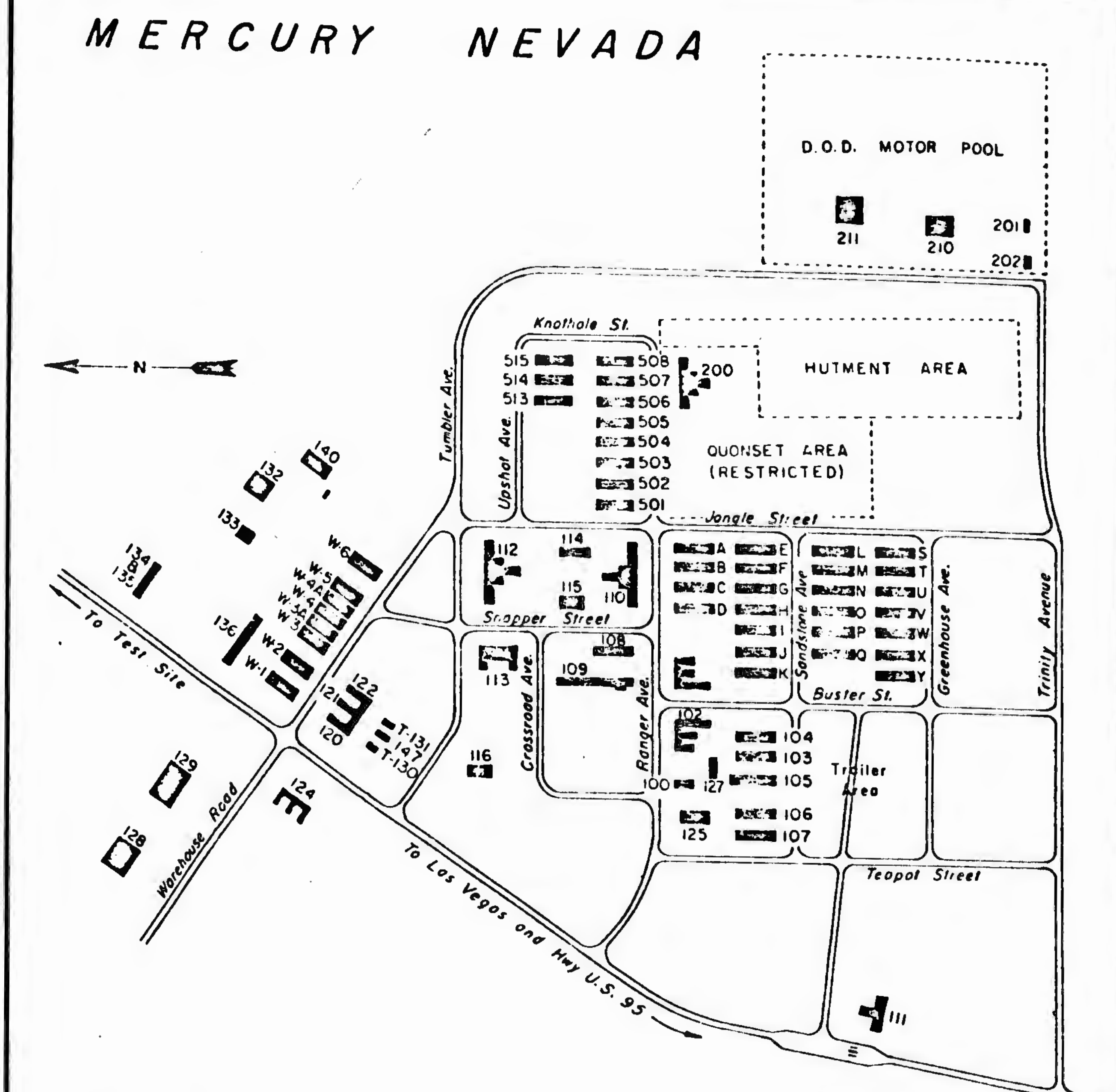
Several meetings were held in an attempt to re-allocate housing among Test Groups and to return some to the Test Manager for his use. This was finally accomplished but most of the participating organizations, after having been allocated blocks of housing, were very unwilling to release portions. In the future, more efficient use of the housing available at the Test Site could be achieved if S-1 were to retain control of about 20 percent of the space allocated to the Test Director to issue on short term occupancy.

Coordination of housing allocation would be made easier if the Test Manager could make his gross allocation to the Test Director somewhat earlier than was the case in Plumbbob. If such an allocation could be made at least sixty days prior to the operational phase the problems involved in sub-allocation would be eased.

OFFICE, LABORATORY AND WAREHOUSE SPACE

The office and laboratory space available to the Test Director was concentrated in the Quonset area, Building 102, and Building 111 in Mercury, and in the CP and Programmatic buildings at the CP area.

The space allocated to each of the groups within the Test Director's organization is shown on page 81. Although this did not comprise the total space requested in the Status Reports, it seemed to serve all participants well and no undue hardship was experienced by any group.



100 — Infirmary
101 — Administration
102 — Administration
103 — Women's Dorm.
Thru
107 — Women's Dorm.
108 — Camp Service, P. O.
109 — Fire Station
110 — Cafeteria
111 — Security
112 — Cafeteria
113 — Recreation Hall
114 — Reefer
115 — Steam Plant
116 — Power Plant

120 — Offices
Thru
124 — Offices
125 — Assembly
127 — Air Weather
128 — Shops
129 — Shops
T-130 LAS
T-131 Office
132 — Motor Maint.
133 — Paint, Body Shop
134 — Oxygen Storage
135 — Helium Storage
136 — Lumber Storage
140 — Vehicle Service Shop

147 — Health & Safety
200 — D. O. D. Administration
201 — Gas Pump
202 — Dispatch Office
210 — Motor Maint.
211 — Warehouse
501 — Men's Dorm.
Thru
515 — Men's Dorm.
A to Y — Men's Dorm.
W-1 Warehouse
Thru
W-6 Warehouse

A to Y-Men's Dorm.

Figure 3-1. Plot Plan of Mercury.

TOTAL SPACE IN SQUARE FEET				
ORGANIZATION	OFFICE	LABORATORY	WAREHOUSE	TOTAL
LASL	2845	800	4000	7645
UCRL	3336	2400	4000	9736
DOD	236 (CP)			236 (CP)
SANDIA	890	266	2000	3156
TG-57	784	1066	0	1850
CETG	3190	3200	250	6640
EG&G	480	1000	500	1980
T. D.	1278	108	0	1386

The earlier allocation, by the Test Manager to the Test Director, of this type of space would result in a much smoother preparation for occupancy. In Plumbbob test personnel were not allocated space until late in the planning period, and as a consequence could not specify communications, furniture, and other support items far enough in advance. This put an extra burden on the Support Director to fullfill all requirements in a short space of time.

VEHICLES

Vehicle requirements were obtained from the Status Reports and after consolidation passed to the AEC to provide. The vehicles which were used were leased on short term by the AEC for this test. Some problems with vehicles were caused by late delivery to the Test Site of vehicles to cover needs of personnel who were in the field at early dates. Once the Operation was in full swing, vehicles offered very little trouble. If it is possible for the AEC in its rental agreement to effect a smoother delivery curve to meet the early requirements and gradually increase to the peak needs, it would eliminate some of the early shortages which were experienced. Sufficient time should always be allowed in the planning to install equipment in the rental cars as required by the experimenters. It took extreme effort by the Support Director's radio organization to get communications installed in the required vehicles.

As the Operation progressed, the vehicle requirements were reviewed periodically and adjustments made where possible to assure effective use of all equipment. The maximum allocation of vehicles to elements of the Test Director's organization was as shown in the table below.

TYPE OF VEHICLE	TG-57	T. D.	LASL	UCRL	SANDIA	EG&G	CETG	DOD	TOTALS
Sedans	12	19	50	62	21	12	38	(Drew	214
Pick-ups	17	4	30	21	20	21	28	Vehicles	141
Station Wagons	4	4	12	17	9	1		from	47
Miscellaneous	10	1	9	3	10	6	26	DOD	65
Total	43	28	101	103	60	40	92	Support)	467

COMMUNICATIONS

S-1 was responsible for coordinating all portable and stationary radio requirements which the AEC furnished, and for the telephone requirements in the space which they controlled.

The telephone system at the Test Site was extended after Teapot with the addition of 100 new lines in the Mercury and CP system. By means of careful allocation of lines, the service adequately covered the needs of the participants. Installation of phone service was often delayed, however, because of the late space allocation problems mentioned above.

Ten communication nets were furnished at the Test Site for communications of all personnel. Five of these nets were made available to the Test Director for allocation. Adequate numbers of mobile units were provided by the AEC although a larger number of units available would have prevented many rush moves of equipment to keep up with the demands. A larger number of spare crystals for the available units would have made the equipment more flexible. Communication equipment was allocated as shown on the next page.

ALLOCATION OF COMMUNICATION EQUIPMENT

USER	MOBILE	REMOTES	BASE	PACK SETS	HANDIE TALKIES	TRANS-CEIVERS
DOD	35	20	5		16	1
TG-57	33	1	2			
LASL	59	22	7	8	8	9
UCRL	58	21	8	2	6	7
T. D.	13	1				
CETG	26	11	4			2
SANDIA	29	10	7	6	4	6
TOTAL	253	86	33	16	34	25

TWX facilities were furnished by the AEC both in Mercury and at the CP. The usage of these facilities at the CP did not live up to expectations and for future operations the requirement for full time coverage of this station should be reviewed.

GENERAL

S-1 was also charged with the responsibility of working with the AEC to make such improvements as were possible in the general living standards at Camp Mercury. The following improvements were instituted: new volley ball, handball, shuffleboard courts, and a golf driving range were built; a recreation supervisor was employed by REECO to organize competitive sports, tournaments, dances, picnics and field trips; the steak house in Cafeteria No. 2 was operated for the entire Operation; male visiting hours in the women's dormitories were relaxed; facilities for cashing personal checks were established; forward area feeding stations for breakfast, lunches, and dinner were established; a personnel-locating service was instituted to handle home and business emergencies; and a picnic area was established. A private car rental service also was offered to participants, but failed to stimulate sufficient interest to warrant its continuance.

It is recommended that sufficient provision be made in future budgets to permit expansion of facilities as follows:

1. Construct a new movie theatre large enough to handle boxing and wrestling matches. The movie theatre should be run by REECO rather than military personnel to avoid the conflict which existed as to proper wearing apparel in the theatre.
2. Establish facilities for the sale of bottled and case liquors, and serve mixed drinks in the recreation hall.
3. Construct swimming pools in Camp Mercury.
4. Install a camp laundry run by the maintenance contractor.
5. Provide more adequate eating facilities in the vicinity of the CP compound.

D. OPERATIONS (S-3)

The S-3 Section was set up in September, 1956 with the following responsibilities:

1. Coordinating the plans of the Test Group Directors and publishing this coordinated information to all interested participants and Test Groups via Operations Plans, Annexes and Test Bulletins.
2. Planning and coordination on dry runs of all types.
3. Detailed movements within the Test Site at shot time (D-1 and D day) for each
4. Coordination of frequencies and frequency interference.
5. Emergency evacuation plans as required.

The S-3 Section started operation in Livermore in late October and moved to Las Vegas about the middle of January. In March, along with the other staff sections, S-3 moved to Mercury. It is recommended that the staff sections originally muster in Las Vegas, moving to Mercury when required.

OPERATIONS

Pre-operational activities consisted mainly in the compiling of overall test information and its dissemination to test participants via the Test Director's Operation Plan, Annex and Test Bulletins. The publication of a chart of accounts in this period was also accomplished. In the future, much closer coordination with the AEC should be obtained in the generation of the chart of accounts. Misunderstandings between the Test Director's staff and the AEC resulted in quite an ambiguous chart of accounts. Closer liaison could have produced a more workable document.

During the operational period, in addition to the duties outlined above, S-3 assumed the job of acting as an information center for test participants. The office, of necessity, was manned almost continually on a 24 hour day, seven day basis due to the compressed shot schedule. Because of this availability of S-3 personnel during the off hours many minor problems were handled in all fields.

One of the major responsibilities during the Operation was the preparation of the shot annexes to the Test Director's Operations Plan. These annexes covered the details of personnel and equipment movement within the shot areas between about 1800 on D-1 through D-day until the area was released by the Test Director. Information of required movements and manned stations was furnished S-3 by the Operations staffs of the various Test Groups. The total requirements were integrated and conflicts resolved prior to the publication of the detailed annex. This annex was then used by the S-3 personnel in cooperation with the Test Site Security Force in controlling access of personnel into dangerous areas.

The Air Operations Officer within the S-3 Section had two general responsibilities: first, to act for the Test Director in all matters pertaining to aircraft safety, interference, and scheduling; and second, to coordinate the user requirements for such support aircraft as L-20, H-21, and sample return planes. During Plumbbob, the Air Support Group (4950th Test Group

Figure 3-2. Support Aircraft Operating from Indian Springs.

from Kirtland AFB) was attached directly to the Office of the Test Manager, and the S-3 Air Operations Officer handled all business between the Test Director's organization and the Air Support Group. Relations were excellent and all support requirements were met.

The problem of frequency allocation, compatability and interference for all participants was another operational responsibility of S-3. The largest single problem in this field was the location (as to source) of spurious and interfering signals which conflicted with signals required by the experimental programs. When one considers that there were an average of 40 RF generating systems operating on each shot, covering a frequency of 150 to 9500 mc, one can see that interference between these signals could be a major problem. For the first shot or two, the location of an interfering signal was an almost impossible job. During the balance of the Operation, the FCWT Communications Officer arranged for the AEC to borrow a military signal source locator capable of detecting signals from 7 KC through 10,000 mc and giving the exact frequency and azimuthal bearing of any signal. After this equipment arrived and was put into service the signal interference problems were much easier to solve. It is recommended that for any future operation of the magnitude of Plumbbob, such interference locating equipment be procured and operated during the entire test period.

Integration of dry runs for all participants was handled by S-3. This was necessary because of the tight schedule, the number of runs required, and the many users of the signal runs. This practice should be continued in any operation where more than one user is involved. Three types of dry runs were involved: first, the signal run which experimenters used to check operation of their equipment; next, the power dry run which was used to check whether sufficient power was available to cover the needs of all participants on a single event; and finally, the frequency dry run in which all participants on a single event turned on whatever frequency generating equipment they intended to use and the general problem of frequency interference was checked.

RECOMMENDATIONS

The Status Reports which all Test Groups filed with the S-3 Section during the planning phase of the operation provided the basis on which all support except construction was founded. The operational period of the test indicated a couple of areas where more complete data on the preliminary reports could have materially eased the pressure. On certain events, classified materials were put in the shot area to test the effect of the weapon on their components. S-3 was not aware that this material was in the field. When time came for recoveries, S-3 was faced with the problem that monitors could not enter the area to survey for safety because they were not cleared for access to the material displayed, and security personnel could not go into the area to guard the material until the area had been monitored. Needless to say, the problem was resolved, but in the future if such displays were noted in the preliminary Status Reports, the problem could be avoided. One additional item of information which would be very valuable on the Status Report would be a statement as to any early or unusual recovery requirements necessary in the acquisition of scientific data. Prior knowledge of these requirements would allow prior planning for their accomplishment in a smoother and easier manner than obtained during Plumbbob.

E. CONSTRUCTION (S-6)

The missions of the S-6 Section were basically to coordinate the construction and support requirements of the various users with respect to scheduling, and to provide and maintain an up-to-date instrument chart showing all stations and the facilities at each station.

The basic policies for the Section were established jointly with the AEC and representatives of the "6" sections of the Test Groups.

These policies established for S-6 were as follows:

1. S-6 was to be a coordinating body only, to handle interferences between user requirements.
2. Each individual "6" section was to have direct contact with the Architect-Engineer (A-E). The responsibility of keeping S-6 informed of arrangements made between the various "6" sections and the A-E was placed on the individual "6" section.
3. S-6 was not to question the requests or designs of the users unless these requests or designs interfered with other users.
4. In the field, S-6 was to coordinate the construction and support requirements of all users and was to maintain control by being the only unit authorized to sign Work Orders.
5. All criteria from users were to be directed to the AEC with information

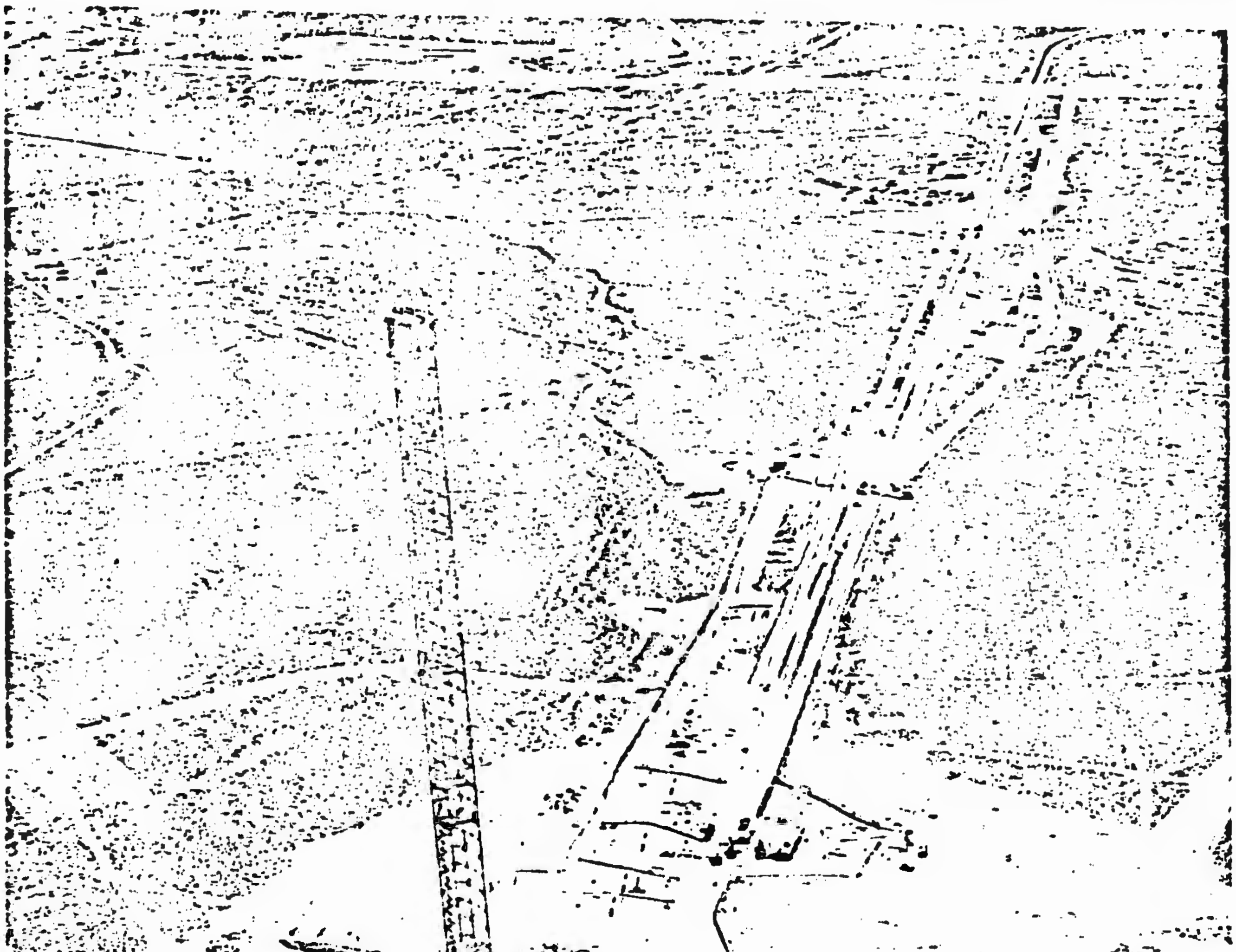


Figure 3-3. Construction Attendant to Tower Erection and Instrumentation.

copies to S-6. S-6 exercised approval of final drawings prior to their being sent to the field for construction.

6. S-6 was to act as an independent body with no ties to any particular participating agency.

Along with the other staff sections, S-6 was formed at Livermore in October of 1956. When the S-6 Section was established, the various users were already in the process of forwarding criteria for construction and forward area communications to the construction contractors since it was necessary that these contractors would have adequate time for construction and procurement. Liaison with the contractors regarding the status of design and construction was accomplished by numerous meetings and trips to jobsite for on-the-job inspections and conferences.

When the S-6 Section and the "6" sections of the various users moved into the field, it was the responsibility of S-6 to provide adjacent office space for the use of the "6" sections from Sandia, UCRL, LASL and CETG. The resulting close contact of the "6" sections greatly facilitated the coordination of requirements and the resolution of problems experienced.

OPERATION

During the operational phase, the prime duties of the S-6 Section were to coordinate the users' support requirements with respect to scheduling and to keep the contractor advised of changes and priorities within the test program. In addition, S-6 continued the preparation and maintenance of the instrument chart and provided the support contractor with consolidated "button-up" requirements for each experiment. Because of the fact that information to be disseminated to various users was normally of interest only to the "6" sections, S-6 used direct correspondence rather than Test Bulletins to convey information. Communications between the S-6 Section and the various contractors was by means of Work Orders which were originated by the various using agencies and then coordinated with the contractors by S-6.

Three major problems were encountered by the S-6 Section during the Operation. These are identified and discussed below.

1. Inadequacy of field inspection by the A-E. The A-E had an insufficient number of inspectors in the field to cover adequately construction in progress. Because of this lack of field representation, there were numerous instances where both the lump sum contractors and the CPFF contractor were working from antiquated drawings. Some structures were not built in accordance with existing drawings and the performed work was of a lesser quality than called for in the specifications. Later in the Operation, the A-E did not provide inspection service on support type Work Orders. As the amount of construction decreased, the A-E discharged inspectors accordingly and consequently never achieved adequate inspection coverage.

   The number of inspectors had been limited by the AEC. By the time the shortage of inspectors was observed, it was too late in the Operation to hire and train additional men. As a result, the "6" section field representatives attempted to observe the details of construction more closely than normally would be required.

2. Inadequacies in work order system. Early in the Operation this problem exhibited two parts: (a) approximately one week was required to process a Work Order from the using agency to the hands of the field construction personnel; and (b) no procedures were set up to handle minor emergency work in the field.

   The excessive time required to process a Work Order arose from the fact that each individual Work Order required an official estimate of cost by the A-E prior to its transmission to the contractor. In order to overcome this a master Work Order was written to cover field support only. The master Work Order carried a cost estimate of all field support that would be required for a two-week period; thereby eliminating the necessity of making an individual estimate on each field support Work Order. In addition, continuing or open Work Orders were prepared to handle such minor work as movement of materials, minor carpentry, electrical and other field support services. These work order numbers were then available to the field personnel, enabling them to take care of minor emergency work.

   Because the open Work Orders described above were available for use by the field personnel without any control from the contractors' supervisory force or the S-6 Section, the construction contractor was placed in a position of being required to do work without any documentation. In order to document the work done by the construction contractor and to insure that instructions were passed from users to contractors without error, it was required

that any work to be done on the open Work Orders be covered by a "buck slip" describing the job to be done.

3. Confusion in the chart of accounts. After construction for the Operation was well underway, the AEC issued a chart of accounts showing the numbers against which each program or project should charge work. This listing was so indefinate as to permit varying interpretations among the groups involved. As a result, it was extremely difficult to review the cost account and insure that all charges against any program, project or structure had been properly allocated. Since time did not permit reissuance of the chart, the only corrective action possible was to have S-6 code all Work Orders in an effort to obtain uniformity in the charges.

CONCLUSIONS AND RECOMMENDATIONS

Based on the S-6 Section's experience during Operation Plumbbob, the conclusions reached and recommendations for future operations are as follows:

1. The basic policy of having the Test Director's staff independent of any of the participating laboratories should be continued.

2. Prior to any future full-scale operation, the quantity and quality of the A-E's inspection force should be verified. It is recommended that an S-6 representative participate in discussions regarding the numbers and types of inspection personnel required.

3. The work order system should be simplified to expedite the processing of user work requests. The simplification could be accomplished as follows:

   a. Eliminate the necessity of estimating each Work Order or increase the number of estimators to speed up the process.

   b. Have all the people required to sign Work Orders in the same building to eliminate the necessity of hand-carrying the orders around for signatures.

4. In conjunction with Work Orders, it is recommended the system of "buck slips" be continued; however, tighter controls on the numbers of "buck slips" should be exercised as follows:

   a. Based on Plumbbob statistics, establish a dollar limitation on the total amount of "buck slips" written over a one-month period. When the dollar limitation has been exceeded, no more "buck slips" can be written until a new fund is available the following month.

   b. Make it mandatory that S-6 approval be obtained if work is to be accomplished on the same date that the "buck slip" is written.

   c. Have the support contractor area superintendent countersign all "buck slip" requests rather than the inspectors.

5. Prior to any future operation, the AEC should attempt to simplify the chart of accounts so as to eliminate the duplications in the available charge numbers. Because the S-6 Section works in such close association with the chart of accounts, a representative from the S-6 Section should participate in formulation of the document.

6. It is recommended that the construction contractor set up an area superintendent with complete control of both manpower and equipment within his area rather than have the work in an area controlled by the various departments such as electrical, mechanical, structural, etc.

7. It is recommended that the S-6 office and vehicles be equipped with three radios, one on the Test Director's net, one on the A-E's net and one on the construction net.

F. RAD-SAFE ADVISORY GROUP

The Test Director was responsibile for all on-site Rad-Safe. Responsibility for on-site radiological safety support was delegated to the Support Director who furnished this support through the facilities of the REECO on-site Rad-Safe Unit.

In addition, the Test Director delegated the responsibility for radiological safety to the various Test Group Directors. Each Test Group Director appointed a Rad-Safe Officer, who handled all radiological safety problems for his group.

The Test Director's Rad-Safe Advisor exercised complete supervision for the Test Director on all radiological safety matters. He also maintained close liaison with the Support Director's Rad-Safe Office and the separate Test Group Rad-Safe Officers to insure full rad-safe support for all personnel in the Test Director's organization.

EXPOSURE GUIDES AND DOSAGE CONTROL

The total permissible exposures to participating personnel were as follows:

1. Gamma: 3.0 roentgens for any consecutive 13-week period, with the further limitation for a calendar year of 5.0 roentgens.
2. Alpha: 10,000 exposure units above background for any consecutive 13-week period computed by multiplying the average air concentration in the area of exposure in $d/m/M^3$ by the hours of exposure. This was used in all cases where personnel were not using respiratory protection in an alpha-contaminated area.

All personnel were issued film badges and charge-a-plates on arrival at NTS. These were worn at all times. Film badges were changed on a monthly basis starting April 1. In addition, film badges were exchanged after each entry into a contaminated area (exceptions to this were made in the case of continuing access permits).

REECO Rad-Safe processed all film badges and submitted dosage records to the Test Director on a daily and monthly basis. Daily dosage reports included only those personnel who turned in film badges on the previous day. Monthly dosage reports contained cumulative dosage information on all personnel in the Test Director's organization. In addition, special reports were issued on all personnel reaching or exceeding the 2.0 roentgen cumulative dose level. These reports were forwarded to Test Group Directors by the Test Director's Rad-Safe Adviser.

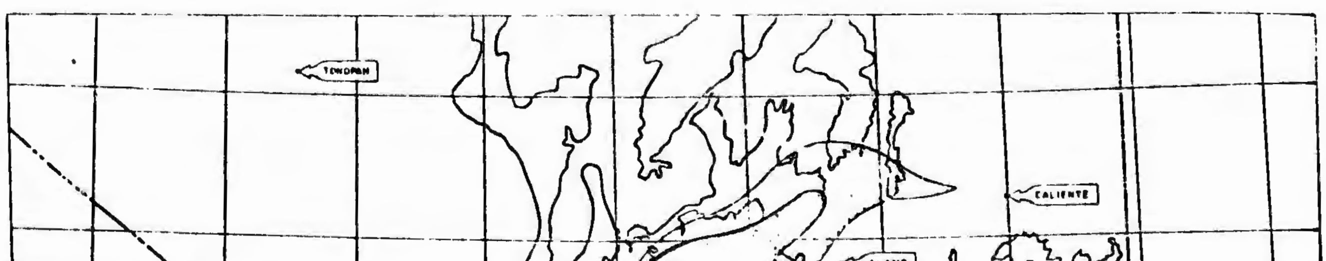


Figure 3-4. Typical Fallout Pattern — NTS.

ENTRY INTO CONTAMINATED AREAS

Radex or radiological exclusion areas were defined as follows:

1. Full Radex Area—Contamination level of 100 mr/hr or higher, or an area where the alpha contamination exceeded permissible levels.
2. Limited Radex Area—Contamination level of 10 mr/hr but less than 100 mr/hr.
3. Non-Radex Area—Contamination level less than 10 mr/hr and when no alpha contamination hazard exists.

Entry into a full radex area required full protective clothing. In addition, a qualified monitor accompanied any party entering a full radex area. Entry into a limited area required such protective clothing and monitoring support as was deemed necessary by the REECO Rad-Safe unit.

Entry of personnel into contaminated areas (full and limited radex areas) required access permits. The access permit signified that all Rad-Safe procedures had been complied with. These access permits were issued to party monitors or party leaders by the REECO Rad-Safe Unit at the Control Point Building 2 (Rad-Safe Building).

Recovery parties were allowed to enter shot areas in accordance with the Test Director's Schedule of Events and the current radiological situation. Actual control of early entry on D-day was exercised by the Test Director's S-3 Section.

Check points for control of entry into contaminated areas were established by the REECO Rad-Safe Unit as required. These check points were located so as to provide control over entry to contaminated areas with a minimum of interference to traffic to and from non-radex areas. All vehicles and parties leaving the contaminated area were stopped at these check points. Vehicles that were found to be contaminated above the tolerance limits were directed to proceed to a vehicle hot-park, or to the Vehicle Decontamination Station for decontamination. After clearance by the check point or decontamination station, personnel exchanged film badges and were monitored at the Rad-Safe Building.

All main access roads were posted at the 10 mr/hr and 100 mr/hr points by the REECO Rad-Safe Unit. These postings were kept current on a daily basis. Any entry into an area contaminated in excess of 10 R/hr had to be approved by the Test Director.

All projects provided their own monitors for entry into contaminated areas. However, some Test Groups were unable to provide a sufficient number of monitors to satisfy their needs, in which case REECO Rad-Safe provided this service.

The project monitors were responsible to the project party leaders who in turn were responsible for the radiological safety of the respective parties.

MISCELLANEOUS

All radioactive material brought onto the Nevada Test Site, with the exception of SS (Source and Special Nuclear) material, was registered by Test Group Rad-Safe Officers with the Test Director's Rad-Safe Officer. This included samples removed from the test area for analysis in other parts of the NTS.

No contaminated material was removed from the NTS without the prior approval of the Test Director or his Rad-Safe Officer. All such materials or equipment removed was monitored, packaged, loaded and labeled so as to satisfy the requirements of the Interstate Commerce Commission regulations for transporting radioactive materials. Arrangements for removal of such contaminated material from the NTS were made by Test Group personnel with the REECO Rad-Safe Unit. Materials excepted from these requirements were SS materials, scientific samples, instruments and equipment designated by the various Test Group Directors.

COMMENTS

The above information outlines in general the scope of responsibility and plan that was followed during Operation Plumbbob.

For the most part, the Rad-Safe program functioned quite smoothly under this plan. However, there were occasions when, no doubt due to the lack of operational experience on the part of REECO Rad-Safe, and Rad-Safe representatives from the various Test Groups, some inconvenience was suffered by several of the Test Groups. After the second shot in the series, though, the system obviously smoothed out and it should be said that the Support Rad-Safe organization did in fact support the Test Director's organization in a very creditable fashion.

G. SAFETY ADVISORY GROUP

In the Plumbbob series of tests two new radically different techniques were employed to reduce radiation fallout or to contain such contamination to the point where it would not be a problem. The use of balloons and tunnels gave many advantages (see Chapter II) but at the same time created a number of safety problems.

There is no built-in system for releasing helium from a balloon should it be considered necessary. It is possible that the collapse of a balloon would be desirable under certain circumstances, while it is still retained by the cables, and of course, it would be mandatory to have a helium release system in the unlikely event that the balloon broke free from the cables with the device still attached.

To have this release control an automobile tire is bolted to the top of the balloon where the folds of the nylon shrouds are gathered. The tire contains a thirty-volt nickel-cadmium battery, relays and a barometric switch. Two nichrome wires, about ten inches long, are placed between the tire and the nylon shroud and are connected to the circuit. The purpose of the wires is to burn through the nylon shroud and the polyethylene liner to release the helium. The circuit is so designed that only one wire is heated, the second is activated only if the first one breaks. To activate this circuit, while the balloon is still fastened to the cables, two buttons on the control console must be pushed. To prevent the balloon from carrying a device off-site, if it should ever break free from the cables and control is lost from the console, the barometric switch would take over and actuate the system at an altitude of 2300 feet above terrain. If the system should fail entirely the balloon would rupture about 5000 feet above terrain.

The present system is the result of many experiments. The first system used only one wire until it was found that the wire tended to break when it was heated and before the many folds of nylon and polyethylene were burned through. Trials were made using prima-cord and blasting caps to blow a hole in the balloon. Finally the two-wire system was chosen as giving the greatest reliability. The optimum result would be a hole in the balloon large enough to bring the balloon down in the Nevada Test Site and still have the balloon come down slowly enough to reduce the chance of a one-point detonation.

The inflation of the balloon and the transfer of the cab containing the test device to the balloon have been done many times and resulted in procedures which have reduced the accident potential to a minimum.

The pre-dawn 1500-foot balloon shots create a hazard of flash over a wide area which could be a hazard to motorists on the public highway. To determine where these line-of-sight areas would cross the highway, a study was made by LASL using topographic maps and assuming a spot 2500 feet above Area 7 C. This study was continued by REECO and some minor changes were made. With the cooperation of local sheriffs and the State Highway Patrol roadblocks were established to halt vehicles prior to their entry into a line-of-sight area. From the reports that were returned after every shot, the motorists were quite appreciative of the information being given to them in the form of a hand-out explaining the reason for the roadblock and a copy of "Atomic Tests in Nevada." To date no incident involving light flash affecting motorists has been reported.

Prior to a tunnel shot the hazards encountered are those normal in the construction of any tunnel with the advantage that the rock formation in this area did not require any shoring except at the mouth of the tunnel where loose rock and earth are to be found. After a shot, however, the problem of re-entry to the accessible parts of the tunnel involves other hazards. There is, of course, the ever present hazard of loosened rock in ceilings and side walls. This was taken care of by scaling off all of this loose material. A greater hazard, however, is the carbon monoxide formed by the explosion which may pocket, possibly to the degree that an explosive mixture may be formed. Even before this would happen, however, there is danger to personnel entering this carbon monoxide area. A careful inspection was made of the tunnel surfaces, carbon monoxide readings were taken and, when necessary ventilation fans were started to clean out the air for the safety of any personnel who were to work in the tunnel.

Entry to the tunnel was strictly controlled by the Test Director and all parties entering the tunnel followed a procedure established for the party. Deviations from this procedure were not permitted. By establishing procedures and working slowly and carefully the post-shot tunnel was made into a safe working area. No radiation problems arose in the Rainier tunnel, but some alpha contamination exists in the Saturn tunnel. From the success of the Rainier shot it seems likely that tunnels for test devices will be used more frequently. The procedures used for reentry into the Rainier tunnel have been reviewed thoroughly and will be a guide to any personnel entering future tunnels.

Safety problems of balloons and tunnels are emphasized in this report only because they were the unknowns in the Plumbbob series. This does not mean that other problems did not exist but the other problems were those that were common to all previous tests in Nevada. Motor vehicle operations are still the largest single problem and they are always emphasized on any Nevada Test Series.

H. CLASSIFICATION ADVISORY GROUP

The responsibility for daily classification during the operation was left with the various operating Test Groups under guidance of the existing classification guides. The Test Director's Office had attached to it a Classification Advisor who was available to assist any personnel of the Test Director's organization with classification problems.

APPENDIX A

AMPLIFICATION OF SHOT SCHEDULE

CODE NAME	FIRED	POSTPONEMENT Date	Time	Reason	LABORATORY
"57"	4/24	Numerous weather and technical delays			Sandia Corp.
Boltzmann	5/28	5/15	5:00 PM	technical	LASL
		5/16	8:00 AM	weather	
		5/17	11:30 PM	weather	
		5/18	4:30 PM	weather	
		5/19	11:40 PM	weather	
		5/20	4:20 PM	weather	
		5/21	4:30 PM	weather	
		5/22	11:20 PM	weather	
		5/23	4:15 PM	weather	
		5/24	11:00 PM	weather	
		5/25	4:20 PM	weather	
		5/26	4:00 PM	weather	
Franklin	6/2	5/24	11:00 PM	weather	LASL
		5/25	4:20 PM	weather	
		5/26	4:00 PM	weather	
		5/27	Boltzmann preferred		
		5/28	4:30 PM	weather	
		5/30	3:55 AM	weather	
		5/30	11:45 PM	weather	
		6/1	3:05 AM	weather	
Lassen	6/5	6/3	6:15 PM	Technical	UCRL
Wilson	6/18	Announced as ready for firing on 6/10			UCRL
		6/10		Technical	
		6/11		Technical	
		6/12		Technical	
		6/13		Balloon weather	
		6/14	11:30 PM	weather	
		6/15	4:30 PM	Balloon weather	
		6/16	4:30 PM	Balloon weather	
Priscilla	6/24	Announced as ready for firing on 6/23			LASL/DOD
		6/23	5:55 AM	weather	
Diablo	7/15	Announced as ready for firing on 6/27			UCRL
		6/26	7:40 PM	Technical	
		6/28	4:45 AM	Technical (misfire)	

APPENDIX A

CODE NAME	FIRED	POSTPONEMENT Date	Time	Reason	LABORATORY
Diablo (continued)		Rescheduled for 7/11 as of 7/8			
		7/10 delayed to 7/12		Technical	
		7/11		weather	
		7/12		weather	
		7/13	10:20 PM	weather	
Coulomb "A"	7/1	Announced as ready for firing on 7/1			LASL
Hood	7/5	Announced as ready for firing on 7/3			UCRL
		7/3	early am	Technical (to 7/5)	
Owens	7/25	Announced as ready for firing on 7/17			UCRL
		7/16	9:30 PM	Technical	
		7/18	4:30 AM	weather	
		7/19	4:30 PM	weather	
		7/20	4:30 PM	weather	
		7/22	4:15 AM	weather	
		7/22	4:30 PM	weather	
		7/23	Kepler preferred		
John	7/1[illegible]	Announced as ready for firing on 7/19			DOD
Kepler	7/24	7/18 delayed to 7/22		Technical	LASL
		7/19 delayed to 7/23		Technical	
		7/22 delayed to 7/24		Technical	
Pascal "A"	7/26	Announced as ready for firing on 7/26			LASL
Stokes	8/7	Announced as ready for firing on 8/5			LASL
		8/5	3:15 AM	weather	
		8/5	4:30 PM	weather	
Saturn	8/9	Announced as ready for firing on 8/9			UCRL
Shasta	8/23	Announced as ready for firing on 7/30			UCRL
		7/29	4:30 PM	Technical	
		7/30	4:30 PM	weather	
		7/31	4:30 PM	weather	
		8/1	4:30 PM	weather	
		8/2	10:30 PM	weather	
		8/3	4:40 PM	weather	
		8/4	10:45 PM	weather	
		8/5	4:30 PM	weather	
		8/6	10:00 PM	weather	
		8/8	3:15 AM	weather	
		8/8	4:30 PM	weather	
		8/9	4:30 PM	weather	

CODE NAME	FIRED	POSTPONEMENT Date	Time	Reason	LABORATORY
Shasta (continued)		8/10	4:45 PM	weather	
		8/11	4:30 PM	weather	
		8/13	4:15 AM	weather	
		8/14	4:25 AM	weather	
		8/14	4:30 PM	weather	
		8/15	10:30 PM	weather	
		8/17	4:25 AM	weather	
		8/17	4:30 PM	weather	(Put back on at 9:30 PM)
Doppler	8/23	Announced as ready for firing on 8/19			LASL
		8/19	3:20 AM	weather	
		8/19	4:35 PM	weather	
		8/20	3:20 PM	Technical	
		8/21	4:30 PM	weather & helium	
Pascal "B"	8/27	Announced as ready for firing on 8/27			LASL
Smoky	8/31	Announced as ready for firing on 8/28			UCRL
		8/27	4:45 PM	weather	
		8/28	4:30 PM	weather	
		8/29	4:50 PM	weather	
Franklin Prime	8/30	Announced as ready for firing on 8/16			LASL
		8/15	4:45 PM	Technical - - for 2 weeks	
		8/28		weather	
Galileo	9/2	Announced as ready for firing on 9/2			LASL
Coulomb "B"	9/6	Announced as ready for firing on 9/6			LASL
Wheeler	9/6	Announced as ready for firing on 9/6			UCRL
Laplace	9/8	Announced as ready for firing on 9/8			LASL
Whitney	9/23	9/11	4:00 PM	weather	UCRL
		9/12	4:00 PM	weather	
		9/13		weather	
		9/14	5:24 AM	Technical	
		9/15	4:00 PM	weather	
		9/16		weather	
		9/17		weather	
		9/19		weather	
		9/20		weather	
		9/21		weather	
Fizeau	9/14	9/11		Technical	LASL
		9/12		weather	
Newton	9/16	Announced as ready for firing on 9/16			LASL

CODE NAME	FIRED	POSTPONEMENT Date	Time	Reason	LABORATORY
Rainier	9/19	Announced as ready for firing on 9/19			UCRL
Charleston	9/28	9/23		Technical	UCRL
		9/25		weather	
		9/26		weather	
Morgan	10/7	10/3	4:00 PM	weather	
		10/4	3:45 AM	weather	
		10/5	1:35 AM	weather	

APPENDIX B
PROGRAM AND PROJECT PARTICIPATION

PROGRAM and PROJECT	"57"	BOLTZMANN	FRANKLIN	LASSEN	WILSON	PRISCILLA	COULOMB "A"	HOOD	DIABLO	JOHN	KEPLER	OWENS	PASCAL "A"	STOKES	SATURN	SHASTA	DOPPLER	PASCAL "B"	FRANKLIN PRIME	SMOKY	GALILEO	WHEELER	COULOMB "B"	LAPLACE	FIZEAU	NEWTON	RAINIER	WHITNEY	CHARLESTON	MORGAN
1.1			X		X	X		X		X	X	X		X		X														
1.2											X	X																		
1.3						X																								
1.4						X																								
1.5						X																								
1.6																														
1.7						X																								
1.8																				X										
1.9														X						X						X		X	X	
2.1			X	X	X	X						X																		
2.2					X			X				X												X						
2.3			X	X	X	X		X		X		X								X				X						
2.4			X	X	X	X		X				X																		
2.5		X	X	X	X			X		X		X																		
2.6			X	X	X	X		X																						
2.7		X		X	X	X		X	X		X	X																		
2.8					X	X		X	X																					
2.9										X																				
2.10		X		X	X			X	X	X	X	X												X						
3.1						X																								
3.2						X																								
3.3						X																								
3.4						X																								
3.5						X																								
3.6						X																								
3.7						X																								
3.8						X																								
4.1			X		X	X																								
4.2		X			X	X		X	X							X														
4.3	INCORPORATED IN CETG PROJECT 33.2																													

PROGRAM and PROJECT	BOLTZMANN	FRANKLIN	LASSEN	WILSON	PRISCILLA	COULOMB "A"	HOOD	DIABLO	JOHN	KEPLER	OWENS	PASCAL "A"	STOKES	SATURN	SHASTA	DOPPLER	PASCAL "B"	FRANKLIN PRIME	SMOKY	GALILEO	WHEELER	COULOMB "B"	LAPLACE	FIZEAU	NEWTON	RAINIER	WHITNEY	CHARLESTON	MORGAN
5.1	X	X		X	X			X		X	X		X																
5.2		X											X																
5.3	X						X	X		X					X	X			X										
5.4	X				X		X	X							X	X			X										
5.5	X	X		X	X		X	X	X	X	X		X		X	X		X	X										
6.1					X																								
6.2			X	X	X		X	X			X				X														
6.3		X	X	X	X																								
6.4	X	X	X	X	X		X	X	X	X	X		X			X		X	X	X	X		X	X	X	X		X	
6.5	X	X	X	X			X	X		X	X																		X
8.1					X																								
8.2			X	X	X		X																						
8.3			X	X	X			X	X	X																			
8.4					X														X										
9.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
10.1	X	X	X	X	X		X	X		X	X		X		X	X		X	X	X		X	X	X	X		X		X
11.1	X	X			X	X	X		X	X		X	X			X	X	X	X	X		X	X	X	X				
11.2	X	X			X	X			X	X		X	X			X	X	X		X		X	X	X	X				
12.1	X									X																			
12.2	X	X			X					X		X	X			X	X	X		X				X	X				
12.3						X						X					X					X							
12.4					X															X			X						
13.1	X	X			X	X				X		X	X			X	X	X		X		X	X	X	X				
13.2	X	X			X	X				X		X	X			X	X	X		X		X		X	X				
13.3	X				X		X	X		X			X			X		X		X			X		X				
14.1	X	X		X				X		X					X					X							X		
15.1	X	X			X	X				X			X			X		X		X		X	X	X	X				
15.2	X	X								X			X			X				X			X		X				
16.1																				X									
16.2	X	X	X	X	X		X	X	X	X	X		X		X	X		X	X	X			X	X	X		X	X	X
16.4										X																			
17.1	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X				
18.1																													

PROGRAM and PROJECT	"57"	BOLTZMANN	FRANKLIN	LASSEN	WILSON	PRISCILLA	COULOMB "A"	HOOD	DIABLO	JOHN	KEPLER	OWENS	PASCAL "A"	STOKES	SATURN	SHASTA	DOPPLER	PASCAL "B"	FRANKLIN PRIME	SMOKY	GALILEO	WHEELER	COULOMB "B"	LAPLACE	FIZEAU	NEWTON	RAINIER	WHITNEY	CHARLESTON	MORGAN
18.2		X	X			X					X			X																
18.3		X	X			X					X			X																
18.4											X																			
19.1						X																								
21.1				X	X	X		X	X			X				X				X		X					X	X	X	X
21.2				X	X	X		X	X			X				X				X		X						X	X	X
21.3									X							X				X								X	X	X
22.1				X	X			X	X			X			X	X				X		X					X	X	X	X
22.2						X		X												X									X	
22.3				X	X			X	X			X				X				X		X						X	X	X
22.4									X							X				X								X		
23.1				X	X	X		X	X			X				X				X		X						X	X	X
23.3				X	X			X	X			X				X				X		X						X	X	X
23.4				X	X			X	X			X				X				X		X						X	X	X
25.1																											X			
26.1																											X			
26.2																											X			
26.3																											X			
26.4a																											X			
26.4b																											X			
26.4d															X												X			
26.4e																											X			
26.4f																											X			
26.5															X												X			
30.1							X		X																					
30.2							X																							
30.3							X																							
30.4							X																							
30.5							X											X			X									
30.5a							X																							
30.6																					X									
30.7																					X									
31.1							X			X		X	X		X		X	X		X	X	X					X		X	X

APPENDIX B

PROGRAM and PROJECT	"57"	BOLTZMANN	FRANKLIN	LASSEN	WILSON	PRISCILLA	COULOMB "A"	HOOD	DIABLO	JOHN	KEPLER	OWENS	PASCAL "A"	STOKES	SATURN	SHASTA	DOPPLER	PASCAL "B"	FRANKLIN PRIME	SMOKY	GALILEO	WHEELER	COULOMB "B"	LAPLACE	FIZEAU	NEWTON	RAINIER	WHITNEY	CHARLESTON	MORGAN
31.2						X																								
31.4						X																								
31.5						X																								
32.1									X							X									X					
32.2		X	X																											
32.3									X		X																			
32.4						X			X		X	X				X														
32.4a																					X									
33.1											X									X	X									
33.2					X	X														X	X									
33.3						X														X	X									
33.4						X															X									
33.5						X														X	X									
34.1						X																								
34.2																				X										
34.3																				X										
34.3a									X					X		X	X		X		X			X	X	X				
34.4																					X									
35.1									X							X														
35.2																				X	X									
35.3																X	X			X	X									
35.4																X	X													
36.1						X														X	X									
36.2						X								X																
36.4																X														
36.5																X														
37.1						X					X					X				X										
37.2		X				X		X	X		X					X				X	X				X	X		X		
37.2a		X				X		X	X							X				X	X				X	X		X		
37.3											X																			
37.4														X			X		X					X	X	X				
37.5																X	X		X											
37.6		X				X		X	X		X					X				X	X									

PROGRAM and PROJECT	"57"	BOLTZMANN	FRANKLIN	LASSEN	WILSON	PRISCILLA	COULOMB "A"	HOOD	DIABLO	JOHN	KEPLER	OWENS	PASCAL "A"	STOKES	SATURN	SHASTA	DOPPLER	PASCAL "B"	FRANKLIN PRIME	SMOKY	GALILEO	WHEELER	COULOMB "B"	LAPLACE	FIZEAU	NEWTON	RAINIER	WHITNEY	CHARLESTON	MORGAN
38.1-I					X	X		X																						
38.1-II						X		X																						
38.2					X	X		X																						
38.3		X			X	X		X																						
39.1			X		X	X		X	X		X			X		X	X		X	X	X			X	X			X		
39.1a						X		X	X		X			X		X	X		X	X	X			X	X					
39.1b						X		X	X		X			X		X	X		X	X	X			X	X					
39.3																					X									
39.4		X	X	X	X	X		X	X		X	X		X		X	X		X	X	X			X	X			X	X	X
39.5			X	X	X			X	X					X			X		X	X					X					
39.6			X		X																				X					
39.6a																									X					
39.7			X																											
39.7a			X		X																									
39.8			X		X																								X	X
39.9		X	X	X	X	X		X	X		X	X		X		X	X		X	X	X			X	X	X		X	X	X
41.1		X														X									X					
41.2																X									X					
50.1		X			X	X		X	X	X	X	X		X			X		X	X										
50.2														X		X	X		X	X	X									
50.3		X	X	X	X	X		X	X	X	X	X		X		X	X		X	X	X	X		X	X	X	X	X		
50.4				X	X	X		X	X	X	X	X		X		X														
50.5		X		X	X	X		X	X	X	X	X		X		X														
50.6		X			X	X		X	X	X	X	X																		
50.7		X	X	X	X	X		X	X	X	X	X		X		X	X		X	X										
50.8					X	X		X	X	X	X	X		X		X	X		X	X	X	X		X	X	X				
52.1					X	X			X	X	X									X										
52.2						X		X																						
53.4					X			X	X		X			X			X		X											
64.1				X	X	X		X				X		X			X		X			X		X		X			X	X
64.2		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	X		X	X	X
64.3		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
64.4				X	X	X		X				X		X			X		X			X		X	X	X		X	X	X

APPENDIX B

PROGRAM and PROJECT	"57"	BOLTZMANN	FRANKLIN	LASSEN	WILSON	PRISCILLA	COULOMB "A"	HOOD	DIABLO	JOHN	KEPLER	OWENS	PASCAL "A"	STOKES	SATURN	SHASTA	DOPPLER	PASCAL "B"	FRANKLIN PRIME	SMOKY	GALILEO	WHEELER	COULOMB "B"	LAPLACE	FIZEAU	NEWTON	RAINIER	WHITNEY	CHARLESTON	MORGAN
71	X																													
72	X																													
73	X																													
74	X																													

END